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Evaluation of a Paint Spray Booth Utilizing Air Recirculation

Engineering-Science, Inc., Arcadia, CA

Prepared for

Industrial Environmental Research Lab.
Cincinnati, OH

Aug 84

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EVALUATION OF A PAINT SPRAY BOOTH UTILIZING AIR RECIRCULATION

by

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Contract No. 68-03-3040, SBE 03

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16. ABSTRACT The objective of this project was to evaluate the effectiveness of the recirculating air spray booth process at the Deere and Company facility in Davenport, Iowa. The effort involved a field measurement program and subsequent analysis of flow rates and emission data from the spray booth to define the degree of enhancement of the emissions stream and permit more efficient and economical control of spray booth emissions.

Energy conservation became a matter of concern for industrial operators during the late 1970s when energy costs began to climb rapidly. Deere and Company engineers noted that heated in-plant air passed through the spray booth to the outside air. If this air could be recirculated while keeping worker environments within safety standards, significant energy cost savings could be achieved with an added benefit of the recirculation scheme being a reduction in emission volume . The reduction in emission volume can result in a significant reduction in volitile organic compound (VOC) control cost since only the quantity of make-up air must be controlled.

Through rerouting the ductwork and modification of operator apparel to ensure worker safety, Deere and Company designed a recirculating air system that was patented in May 1981. Included in the design is a bleed stream which controls VOC buildup in the recirculating system by routing a portion of the air to a natural gas burner where it serves as combustion air and destroys the entrained VOC.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This project evaluated a new concept that may enhance the reduction of volatile organic compounds (VOC) emissions from metal spray coating operations. The technology and operating system was developed by Deere and Company of Moline, Illinois and is in place at their Davenport, Iowa facility. The system utilizes the concept of air recirculation to reduce the amount of gases exhausting to the atmosphere that must be controlled. This report documents a field testing program developed to establish the range and limitations of the system.

Requests for further information regarding the pollution abatement concept discussed in this report should be directed to Charles Darvin (513) 684-7506, IERL, Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

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ABSTRACT

The objective of this report was to evaluate the effectiveness of the recirculating air spray booth process at Deere and Company facility in Davenport, Iowa. The effort involved a field measurement program, subsequent analysis of flow rates and emission data from the spray booth to define the degree of enhancement of the emission stream and to permit more efficient and economical control of spray booth emissions.

Energy conservation became a concern for industrial operators during the late 1970's when energy costs began to escalate rapidly. Deere and Company engineers recognized that heated in-plant air passed through the spray booth to the outside. By recirculating the air that escaped while keeping worker environments within safety standards, significant energy cost savings could be achieved with the added benefit of the recirculating scheme being a reduction in emission volume. The decrease in emission volume can result in significant reduction in volatile organic compound (VOC) control cost since only the quantity of make-up air must be controlled.

Through rerouting the ductwork and modification of operator apparel to ensure worker safety, Deere and Company designed a recirculating air system that was patented in May, 1981. The design includes a bleed stream which controls VOC buildup in the recirculating system by directing a portion of the air to a natural gas burner where it serves as combustion air while destroying the entrained VOC.

This report was submitted in fulfillment of Contract No. 68-03-3040 and Work Assignment No. SBE03 by ACUREX under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 6/82 to 12/83, and work was completed as of 12/83.

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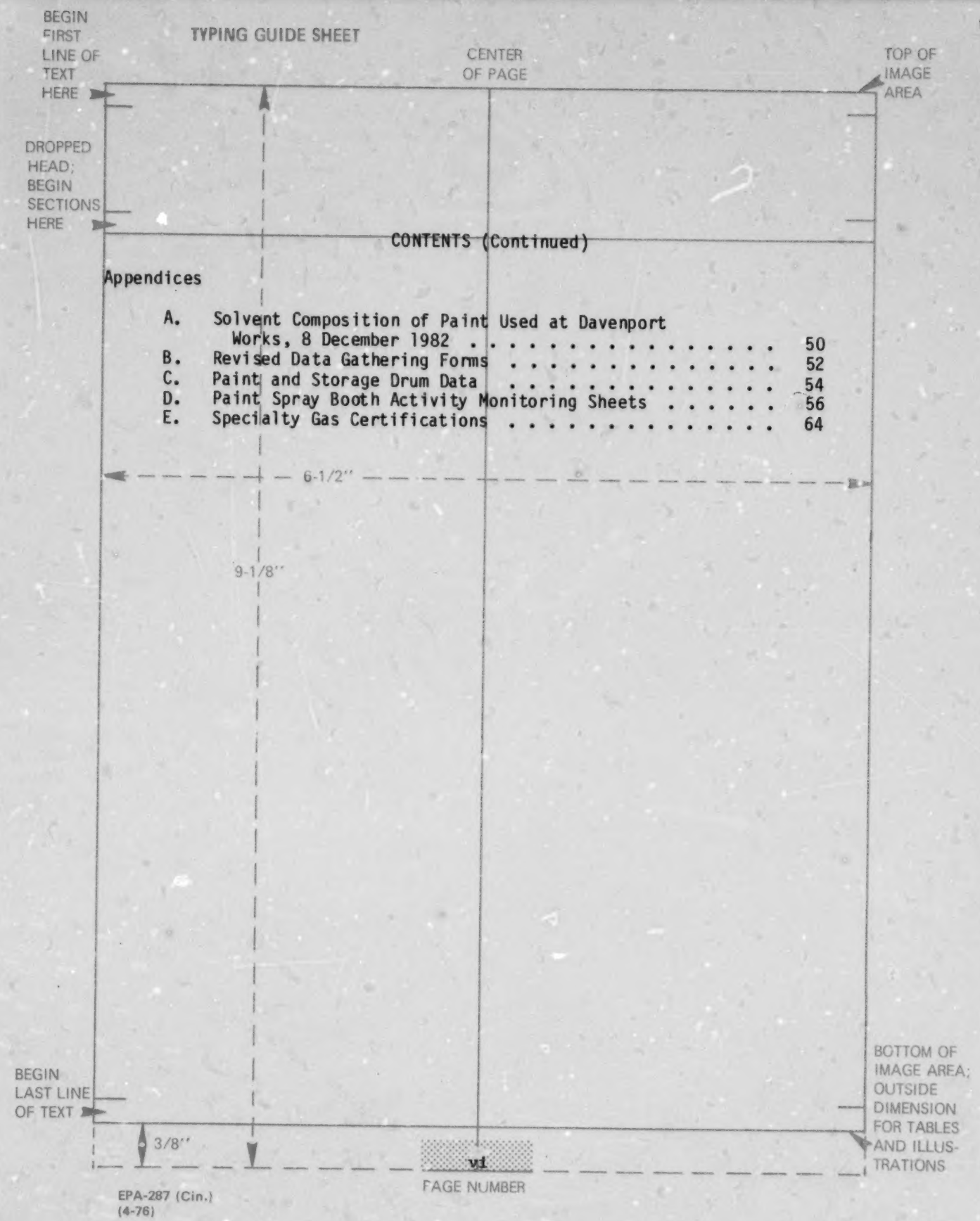
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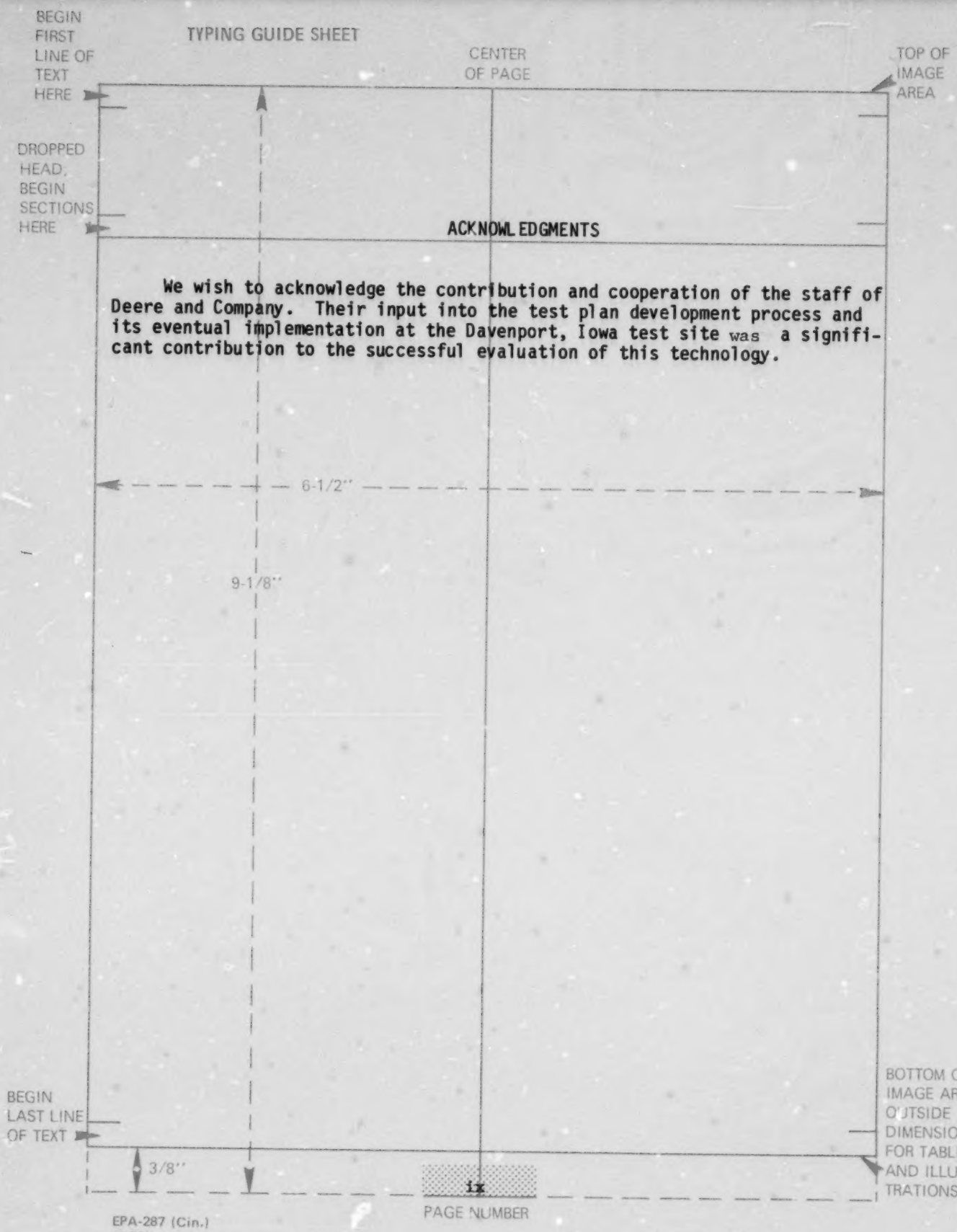
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We wish to acknowledge the contribution and cooperation of the staff of Deere and Company. Their input into the test plan development process and its eventual implementation at the Davenport, Iowa test site was a significant contribution to the successful evaluation of this technology.
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SECTION 1

INTRODUCTION

The use of spray applicators in enclosures or booths to transfer paint coatings to various surfaces has been common for a number of years. One result of these paint transfer activities is the generation of air contaminants when solvent-based paints are used. The discharge from a paint spray booth consists of particulate matter and organic solvent vapors. Evacuating these pollutants from the booth environment is achieved using exhaust blowers. If the booth is of substantial size, evacuated air volumes can be significant. The costs associated with evacuation are a function of volumes exchanged, path of outside replacement air into the booth and environmental control requirements for the solvent-laden exhaust gases. Where the make-up air is supplied directly from the outside ambient air, the energy loss related to utilization of heated air can be very important in cold climates.

The U.S. Environmental Protection Agency (EPA) Industrial Environmental Research Laboratory (IERL-Ci) which is constantly searching for innovative cost-effective means to more efficiently control sources of air contaminants, was interested in evaluating the air recirculation approach as a method to reduce the exhaust gas volume from paint spray booths. This approach may render the booth more amenable to economical VOC control using typical control technologies, such as carbon adsorption or incineration.

Engineering-Science (ES) was issued Work Assignment No. SBE03 under Contract No. 68-03-3040, to evaluate the effectiveness of a recirculating air paint spray booth at the Deere and Company facility in Davenport, Iowa. The scope was limited to a one-week field measurement program with subsequent engineering analyses of flow rates and VOC emission data to project the positive and negative attributes of such a system for spray booth applications.

An initial site survey was conducted in July 1982 and a test plan was developed to evaluate the paint spray booth system. The plan, approved on December 1, 1982, was designed to focus on operating parameters such as:

1. quality of paint used during the test periods;
2. number and type of parts painted;
3. air flow and recirculation rates in the spray booth;

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4. bleed stream air flow rates and VOC concentrations; and

5. natural gas burner efficiency for combusting the VOC bleed stream.

The field evaluation program was conducted between December 13 and 17, 1982. The test protocol and data gathering procedures had to be modified in the field but testing continued on schedule. Because of the business recession and the very slow production rates at the Deere and Company plant, three operational limitations were noted, upon the field team's arrival, which restricted the process variables during the testing program and forced changes in the test protocol:

1. Large equipment inventories and reduced production rates resulted in low paint spray booth utilization;

2. Reduced production rates precluded stockpiling of similar materials for passage through the paint spray booth or scheduling of a selected paint type at any given time;

3. Reduced production rates precluded the selection of the type of paint and solvents to be used during the tests.

Section 2 of the report provides a general background on paint spray booths, the Deere and Company concept for recirculation of air in a paint spray booth, and a description of the Davenport, Iowa facility which was evaluated. Section 3 describes the test protocol, the sampling methodologies, quality control procedures, and test site evaluation. Test results appear as Section 4 with an evaluation of the system performance presented in Section 5. A discussion of potential alternate control applications for the recirculation technology exhaust stream appears as Section 6. Section 7 of the report presents a summary of conclusions.

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SECTION 2

CONCLUSIONS

The following conclusions were based on an evaluation of the air recirculation system of a paint spray booth utilized by Deere and Company at their Davenport, Iowa plant:

1. Make-up air for the paint spray booth was reduced by approximately 90 percent from the original operating mode by utilizing air recirculation, without creating adverse effects on product quality, worker health, or plant safety;

2. Since only approximately 10 percent of the total booth air flow results in emissions to the atmosphere, air pollution control equipment to destroy the hydrocarbons from this paint spray booth would need to be only about 10 percent of the size and cost of a system for a spray booth without air recirculation;

3. Solvent concentrations can be enhanced significantly, making potential control systems more cost-effective.

4. Paint colors and types were changed at frequent short-term intervals without affecting product quality;

5. Energy savings of the recirculation system was attributed primarily to reduced heat for make-up air during the winter months;

6. The use of recirculation in the spray booth permits numerous booth VOC control scenarios such as destruction of VOC by oven burners, by water cleaner burners (as done at Deere), by incineration, or by carbon adsorption.

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SECTION 3

BACKGROUND

PAINTING OPERATIONS AND SPRAY BOOTHS

The selection of paints and other surface coatings for application on metal and other parts is a critical element of the metal coating industry. In many cases the coatings must provide aesthetic appeal, but primarily, they must protect the metal from the atmosphere in which it will be used. Each metal coating line is different, following the dictates of market demands. However, certain operations are relatively common throughout the industry, such as cleansing the metal substrate to remove grease, dust, mill scale, or corrosion. In many instances, it is pretreated to improve adhesion. Methods commonly employed include a multiple stage cleaning sequence alternating caustic and phosphate solutions with water. Surface drying of parts after cleaning is achieved by passage through an oven or air drying before coating application.

The most common method of coating application is spraying, with flow coating and dipping procedures used less frequently. Spray coating provides a transfer efficiency that varies with the method of application and the part being coated. One indication of transfer efficiencies is presented in Table 1, taken from EPA document AP-40, "Air Pollution Engineering Manual", page 861.

TABLE 1. TRANSFER EFFICIENCY AS A FUNCTION OF SPRAYING METHOD AND SPRAYED SURFACE* (PERCENT)

Method of Spraying	Flat Surfaces	Table Leg Surface	Bird Cage Surface
Air Atomization	50	15	10
Airless	75 to 80	10	10
Electrostatic			
Air-atomization	75	65	65
Airless	80	70	70
Disc	95	90 to 95	90 to 95

* Values presented in this table are not to be considered indicative of Deere and Company operations.

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Spray coating is performed in a booth because of the following reasons:

1. the enclosure contains the overspray, reducing the impact of the activity on other operational practices;

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2. use of an enclosure contains the particles and solvents, keeping them from entering the plant environment and affecting worker health and safety;

3. use of an enclosure improves the product quality by minimizing the possibility of contamination due to dust or other airborne materials;

4. the enclosure allows operators to control, through temperature and flow, the atmosphere in which the coating is applied and cured.

To maintain the spray booth in a manner that will reduce its impact on other process operations a blower is installed to evacuate the booth air. The volume exchange creates a negative pressure at the face of the booth, thus eliminating the need for further protection of the other work space. Minimal acceptable air quality standards inside the spray booth as outlined under requirements of the Occupational Safety and Health Administration (OSHA) dictate the sizing of the evacuation system so that concentrations do not exceed approved levels.

Exhaust gas discharged through the blower can involve significant volumes of air and can contain appreciable amounts of solvent vapors and paint particles. Air pollution regulations in some states or localities may require that control equipment be installed to reduce such emissions. Depending on the air volumes and pollutant concentrations involved, the cost of air pollution control can be significant.

DEERE AND COMPANY TECHNOLOGY

Deere and Company engineers began to examine cost associated with loss of heated air from paint spray booths to the outside atmosphere in the late 1970s when plant operators saw spiralling energy costs in the future. It was speculated that, during winter, significant energy saving could be achieved if these volumes of air were recaptured and plant air changes reduced. While the energy savings aspect of the system would be the primary motivation behind the effort, Deere and Company engineers appreciated the need in the modified system to assure continued operator confort and safety and continued product quality. The result of their deliberations was a design for a recirculating air system granted United States Patent 4,266,504 on May 12, 1981.

The Deere and Company solution focused on the existing practice during wintertime of supplying the spray booth with heated replacement air from the in-plant environment. The Deere and Company concept was premised on shutting

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down the "once-through" process, eliminating the need for the heater house and the exhaust stack. Recirculation of the paint spray booth air would increase the solvent concentrations which raised concerns of worker exposure and safety. It was decided that the workers could not operate safely within the newly created higher solvent concentration environment, thus they were provided an artificial air supply. Deere and Company engineers provided the workers with an air pressurized hood apparatus consisting of an air cooler, oil, water and odor filter, and a carbon monoxide monitor and alarm.

If recirculation of solvent-laden air were to continue indefinitely, concentrations of solvents would approach the lower exposure limit (LEL). The Deere and Company recirculation concept controlled the build-up of solvent concentrations using a small bleed-off fan which ducted a quantity of booth air recirculating in an overhead plenum to the water heater of a nearby parts washer. This volume of solvent contining air provided the combustion air for the gas fired water heater which simultaneously destroyed the entrained solvents. To ensure that booth solvent concentration levels did not experience a rapid buildup approaching explosive levels, a lower explosion limit monitor was installed to continually sample booth air. The instrumentation was adjusted so that if it sensed 25 percent of the lower explosive limit of the solvents in the air, it would automatically open all dampers and return the spray booth to a conventional "once-through" operation. If this occurred, an alarm would sound, warning the workers to leave the booth.

POTENTIAL VALUE OF TECHNOLOGY

The most significant potential value of the recirculation system is that the volume of contaminated air leaving the booth is substantially reduced (about 90 percent at Davenport). Smaller air volumes at higher solvent concentrations allows for design and installation of smaller, more cost-effective air pollution control equipment such as incinerators or carbon adsorption units to achieve mandated limitations on discharges of air contaminants to the atmosphere.

Another potential value of a recirculating paint spray booth is the gross reduction in exhaust volumes. This savings in air volume provides a significant wintertime cost savings due to reduced air heating loads. The total saving are made up of the following:

1. Electrical consumption would be reduced by shutting down some of the motors and fans that were originally used to serve the paint spray booth; and

2. Heat consumption for room ventilation air would be reduced by approximately 90 percent since 124,000 cfm of air would not have to be heated during the winter months.

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DAVENPORT FACILITY HISTORY AND DESCRIPTION

The Deere and Company paint spray booth design modification at the Davenport, Iowa plant was performed on an existing system designated Paint Spray Booth 777. Prior to modification, the booth contained six blowers, each designed to move upwards of 627 m^3 (22,000 ft^3) per minute through the booth for a total blower capacity of 3,736 m^3 (132,000 ft^3) per minute. The spray booth modification included construction of an overhead plenum capable of capturing up to 2,280 m^3 (80,000 ft^3) per minute of exhaust air. The exhaust ducts were then sealed and three of the exhaust blowers designated Northwest No. 1, Southcentral No. 4, and Northeast No. 5 were decommissioned (Figure 1). A bleed stream of 43 m^3 (1,500 ft^3) per minute was drawn from the booth atmosphere to prevent a buildup to unacceptable VOC concentrations. This stream was routed to the washer pretreatment system burners where the gas stream provided combustion air to the burners and simultaneously destroyed the entrained VOC. Two of the five burners in the system were designed to operate at either a low or high fire setting. When parts movement through the pretreatment oven was slow, operational temperatures could be maintained by use of low fire on the burners. At low fire, the bleed stream flow rate was designed to provide the theoretical air necessary to combust the natural gas fuel and VOC mixture. At high fire, natural gas flows would increase and since bleed stream air remained constant, supplemental outside air would be supplied through a blower to maintain a proper combustion mixture.

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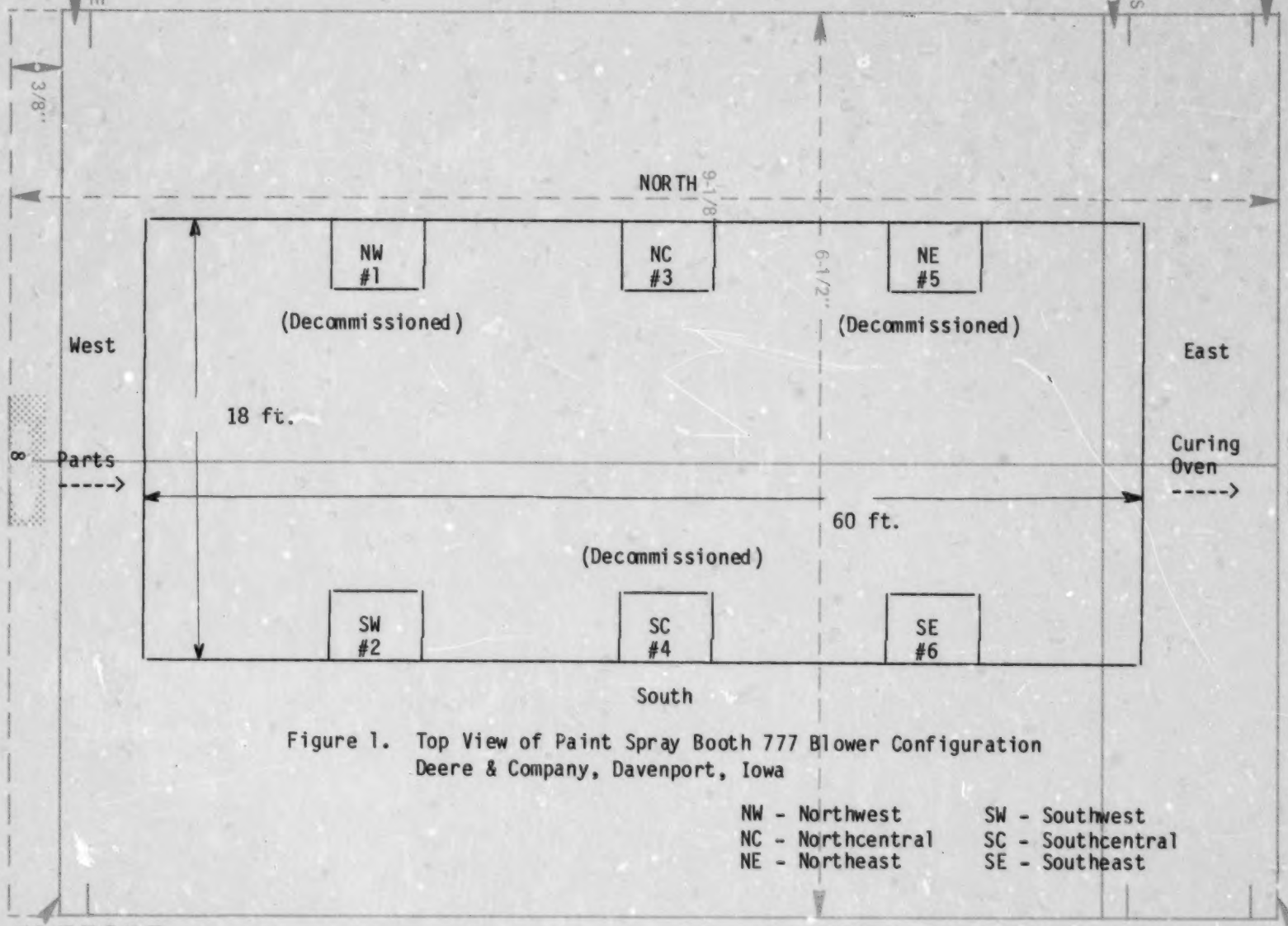

Figure 1. Top View of Paint Spray Booth 777 Blower Configuration
Deere & Company, Davenport, Iowa

NW - Northwest
NC - Northcentral
NE - Northeast
SW - Southwest
SC - Southcentral
SE - Southeast

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SECTION 4

TEST SITE DESCRIPTION AND TEST PLAN DESIGN

DAVENPORT SYSTEM DESCRIPTION

Spray Booth Design

The paint spray booth is a tunnel type production booth measuring 18.3 m (60 ft) in length and 5.5 m (18 ft) wide (Figure 2). The booth can accommodate from one to four painters depending on production demands, part type, size and complexity. The booth incorporates a downdraft air recirculation system with the exhaust air passing through a below-floor level water wash section. Air is recirculated with three separate blowers discharging into a common overhead plenum designed to handle up to 2,264 m^3 (80,000 ft^3) per minute. Recirculated air passes through two sets of filters aligned in series to remove residual paint aerosols that may escape the water wash. A bleed stream from the recirculating plenum is routed through an auxiliary blower to the two variable fired natural gas burners where the bleed air is utilized in a heated pretreatment water bath.

A drying oven is connected directly to the spray booth. The oven exhaust system is set so that some booth air is drawn into the oven section which prevents heated oven air from flowing back into the spray booth. This flow has not been precisely measured but is estimated by Deere and Company engineers to range up to 142 m^3 (5,000 ft^3) per minute.

Parts Painting

Spray coating of parts is performed by painters using hand-held spray guns. Both conventional air and electrostatic guns are employed. The predominant paints applied during the test period were primer and enamels exhibiting traditional green characteristics of John Deere. The next highest usage is a medium solids industrial yellow (both enamel and primer). Paints and solvents used at the Davenport works of Deere and Company are listed in Appendix A. Paint consumption traditionally is not measured directly by company personnel but is estimated by the cost accounting department to be about 50 gallons per painter per shift. During the program two painters were assigned to the spraybooth. To allow the painters

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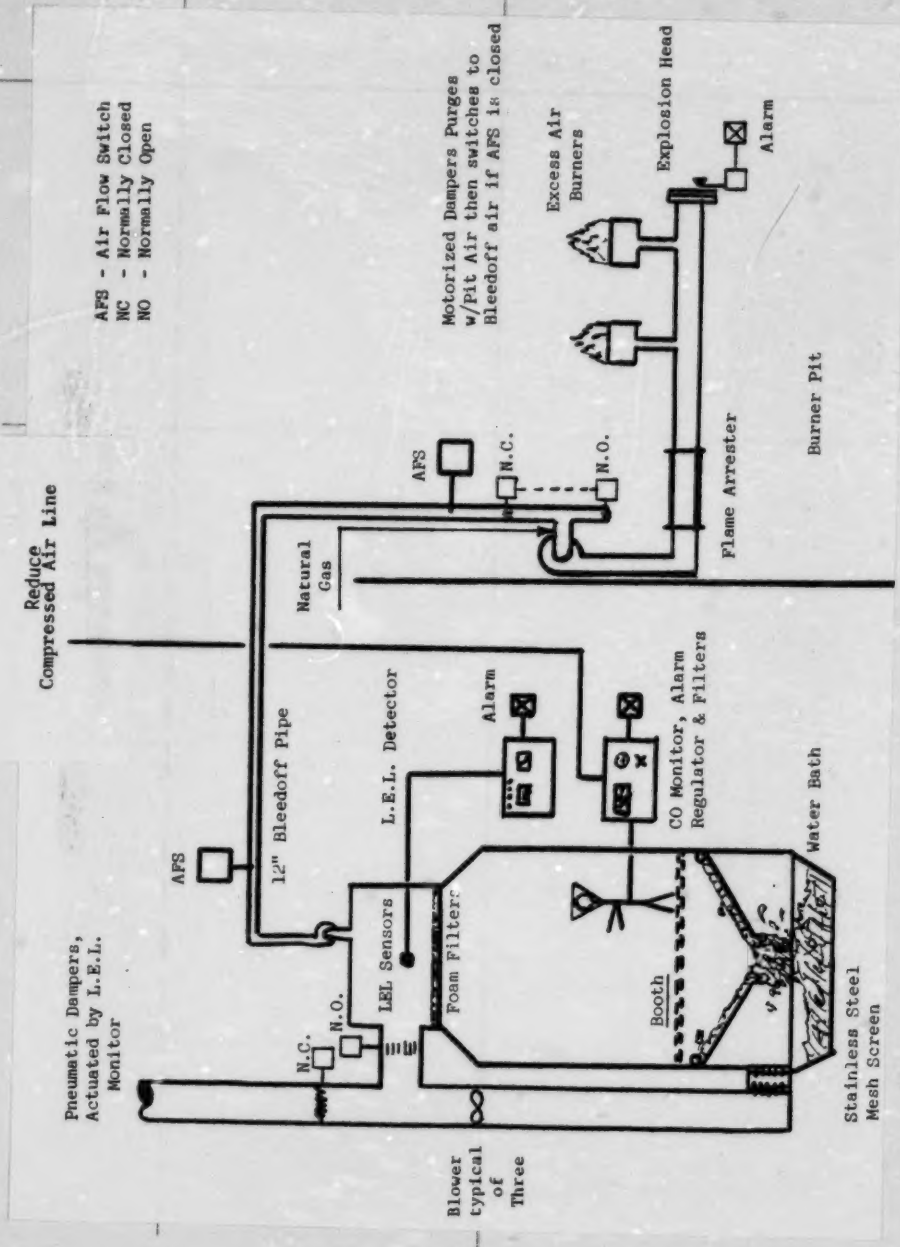

Figure 2. Schematic Diagram of Recirculating Spray Booth

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to operate in an environment with elevated solvent levels, each painter is provided a hood with a separate hose feeding a purified air supply at a rate of 0.5 m^3 (16 ft^3) per minute.

Bleed Air Control System

A design maximum of 43 m^3 (1,500 ft^3) per minute of the recirculating air is bled off the spray booth plenum to burners firing a heated wash tank. This volatile organic compound (VOC) laden air is used as combustion air in two of the five burners in operation. The two burners can operate at either high or low fire and utilize the constant volume of bleed stream air with automatic adjustment of the air/fuel ratio. Initiation of one of the two firing rates is dictated by a control system designed to maintain a constant temperature in the water bath. As designed, at the low fire setting, the necessary combustion air is supplied by the bleed stream. However, when high fire operation is demanded, a pressure blower supplies the required supplemental air from outside to burn the additional natural gas.

The burners fire into 0.3 m (1 ft) diameter submerged pipes running for a length of 21 m (70 ft) on the underside of the bath. After exiting from the bath, the individual burner pipes discharge combustion gases to an exhaust stack through a transition header. Exhaust temperature is about 505 ^oK (450 ^oF).

PROCESS VARIABLES

The test plan was designed to focus on variations of the key operating parameters such as:

- paint types and usage during test periods
- number and types of parts handled
- recirculation rate of paint spray booth air
- bleed stream flow rate and VOC concentration
- burner VOC destruction efficiency

TESTING APPROACH

The test plan incorporated the relevant elements of a quality assurance project plan as specified in "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans," QAMS-005/80, OMSQA, ORD, U.S. EPA, Washington, D.C., December 29, 1980.

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The test plan approach was keyed to obtain data on specific aspects of the Davenport design as follows:

- exhaust and recirculating system flow parameters
- concentration of VOC in key portions of the system
- destruction efficiency of the burner system for VOCs under various operating and load conditions

A simplified flow schematic to illustrate flow and VOC paths is presented in Figure 3. The test points and parameters to be tested are presented in Table 2.

TABLE 2. TEST POINT LOCATIONS AND PARAMETERS

Parameters	Locations		
	Recirc. Duct (3)	Bleedoff to Burners (1)	Burner Exhausts (2)
Velocity	X	X	X
Duct Area	X	X	X
Temperature	X	X	X
Moisture Content	X	X	X
VOC Concentration			
Continuous FID		X	X
Speciation (grab)		X	X
CO_2			X
CO			X
O_2			X
Paint			
Consumption			
VOC Content			
Type application			
VOC on parts			
VOC in wash water (estimate)			
LEL Readings	Measured by plant Leeds and Northrup Combustible Gas Analyzer		

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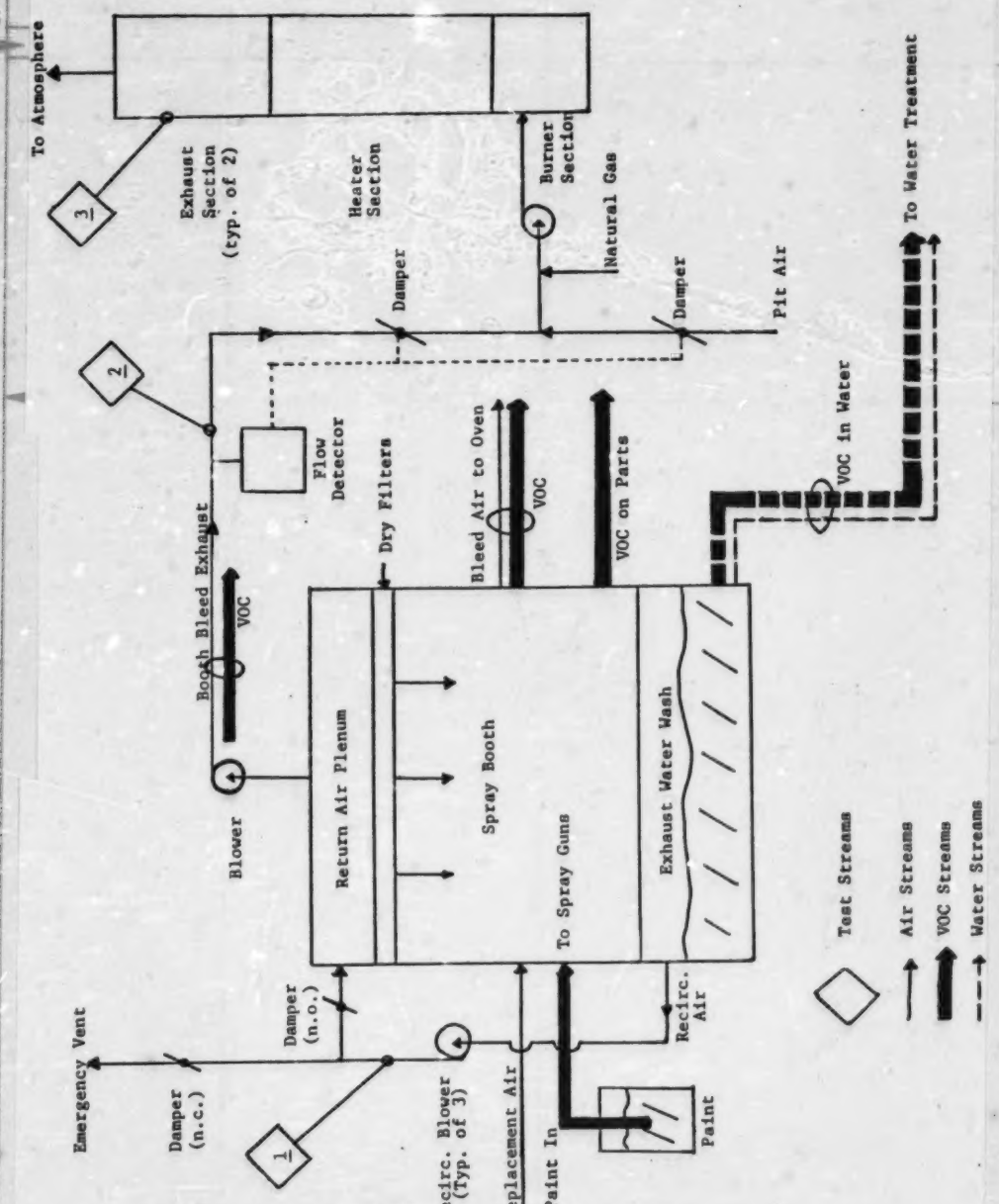

Figure 3. Air and VOC Flow Schematic

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Major attention was devoted to the impact of the operating and load conditions on the VOC concentrations in the booth bleed air stream to the burners and the burner firing rate. Obviously, VOC concentrations would be influenced by paint application rate, VOC content of the paint, and the amount of overspray. It was realized that company production limitations at the time of the test due to high inventories would not allow for complete control of all parameters in advance. However, an attempt was made to schedule production so that conditions of paint application rate, type of paint, and type of spray guns would be kept constant over one-half hour time blocks. Using this strategy, tests were planned over a range of VOC conditions to determine the combinations of activities and materials that generated the high and low extremes of changes in VOC concentration. Included were tests at both high and low fire settings on the exhaust burners. Automatic controls normally switch between high and low fire settings to maintain constant wash tank water temperature. However, during the tests, controls were operated manually to maintain constant firing rate during any desired test period. Therefore, tests were conducted at the four combinations of high and low exhaust burner rate coupled with high and low VOC release rates from the paint spray booth.

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In addition to data gathered in the field by the evaluation team, process and operational data were obtained from Deere and Company. These included:

1. Paint application rate
2. Paint type (solvent composition and type)
3. Spray gun type
4. Number and location of paint spray personnel in booth
5. Estimates of amount of paint on the products actually painted (amount of paint applied per part)
6. Number of parts painted during each test (including type and identification number)
7. Burner operating conditions

Overspray was entrained in the water wash below floor level. However, it was expected that the amount of VOC reaching the atmosphere from this source was quite small since the solvents involved were not considered highly soluble in water. To confirm this, VOC levels were checked in the air space above the water skimming tank using a hand-held VOC meter (OVA type).

To achieve the measurement goals set forth in the objectives and the parameters identified in Table 2, sampling sites were selected that would be representative of the recirculating spray booth technology under examination.

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The specific sampling procedures and analyses were conducted on-site, eliminating the need for transport or overnight storage of VOC bag samples (Table 3).

TABLE 3. SAMPLING METHODS AND PROCEDURES

Sample Type	Method
Gas analysis for Carbon Dioxide and Oxygen	EPA Reference Method 3, sample taken from burner exhaust stack in integrated bag sample.
Volatile Organic Compound (VOC)	1. Booth Bleed Stream (system described in Figure 4). Sampled through heated (350°F) sampling lines to prevent condensation of heavier organic compounds. Samples taken continuously using a heated pump for analysis by continuous Flame Ionization Detector (FID). Portion of sample diverted to Tedlar bag for speciation using gas chromatography (speciation only) 2. Burner Exhaust Stream Integrated bag sample collected for CO_2 and O_2 Orsat determination are used as source of samples for total VOC using the FID and for methane using gas chromatography.
Moisture Content	EPA Reference Method 4
Stack Gas Velocity and Volumetric Flow	EPA Reference Method 2

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The only booth analytical instrumentation was a Leeds and Northrup combustion gas analyzer. This single analyzer cycled among four points, including the return air plenum. Readout was given on a percent of LEL basis. The analyzer was calibrated with hydrogen in air from a compressed gas cylinder. The cylinder in place at the time of the pretest survey was marked as containing 1.02 percent H_2. Deere and Company officials stated that the analyzer was set to read 25 percent of scale using this calibration

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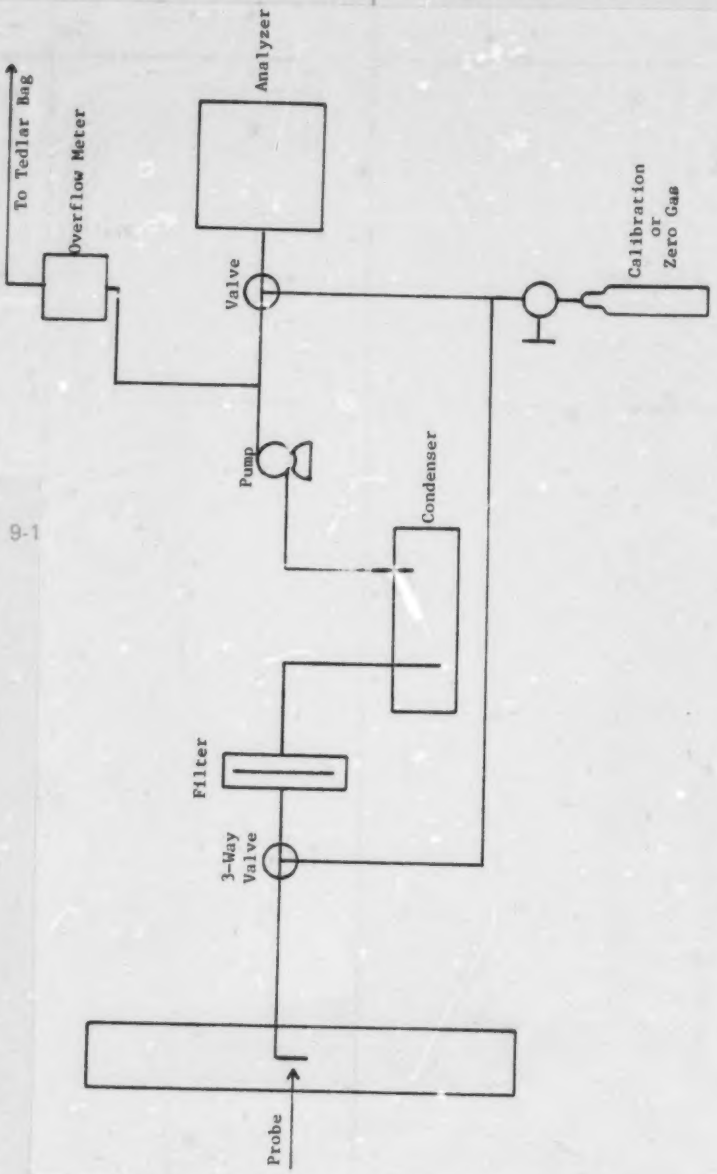

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Figure 4. Schematic of Sampling System

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gas. (Note: the LEL for hydrogen is commonly given as 4 percent by volume in air.) This instrument was not utilized by the test team in the evaluation of the recirculation system.

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ANALYTICAL PROCEDURES

Analyses were conducted for the following compounds or classes of compounds: 1) carbon dioxide and oxygen by Orsat; 2) total volatile organic compounds by flame ionization detector; and 3) methane by gas chromatography. The specific methods are discussed in the following sections.

Carbon Dioxide and Oxygen by Orsat Analysis

The procedure for this analysis is described in EPA Method 3. It involves introducing a sample of stack gas collected in a flexible bag to the Orsat apparatus. The gas sample is manipulated from the gas burett to selective absorbing reagents, and the concentration determined volumetrically by difference from the original volume after each absorption step. Samples were held between 30 minutes and 4 hours before analysis. Care was taken to avoid any air infiltration after sample introduction. The analyses were conducted at constant temperature and pressure.

Total Volatile Organic Compounds

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The flame ionization detection (FID) method of analysis was used instead of EPA Method 25 for total non-methane organic compounds measurements for the following reasons:

1. VOC concentrations in the bleed stream from the booth are relatively low in concentration (previous tests showed most values below 1000 ppm). Recent work[1]) has shown that Method 25, when used for low concentrations, has significant variability due to differences in compound oxidation efficiency and to the difficulty in completely purging CO_2 from the cold trap used to collect condensibles. Any CO_2 not purged is erroneously reported as VOC.

2. The FID approach is much simpler to use than Method 25 and there is less chance for manipulative errors.

The analyzer was run in a continuous mode on the bleed stream from the spray booth. It was calibrated with the solvent of interest and routinely checked with a methane standard.

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1) "Validation of EPA Reference Method 25 - Determination of Total Gaseous Non-Methane Organic Emissions as Carbon," G. B. Howe, S. K. Gangwal, R. K. M. Jayanty, J. E. Knoll, and M. R. Midgett, Paper 82-58.6, presented at 75th Annual Meeting, APCA, New Orleans, June 1982.

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Speciated Volatile Organic Compounds

Bag samples were collected for analyses using a Carle Model 211 located onsite. One of the following columns was used, depending upon the exact solvent composition.

1. GP 10% TCEP on 100/120 Chromosorb P AW, 8' x 1/8" S.S.; column temperature 80°C; flow rate - 20 ml/min;

2. GP 10% SP-1000 on 80/100 Supelcoport, 20' x 1/8" S.S.; column temperature 100°C; flow rate - 30 ml/min.

In this study, the speciation analysis was used to obtain the ratios of known unmodified solvent constituents in the spray booth bleed stream. The goal of the analysis was not to attempt to identify species present in an unknown sample. The ratio data together with individual FID response factors established during calibration would be used to calculate the concentration of each species contributing to the total VOC concentration as measured by FID.

Methane

A bag sample was collected from the burner exhaust and analyzed for methane using gas chromatography. Analyzing the exhaust stream using the FID while providing an indication of overall hydrocarbon concentration difference, does not allow for direct determination of VOC destruction efficiency.

The only hydrocarbon expected in the burner exhaust that was not present in the bleed stream was methane. By measuring the collected bag sample through the FID for total hydrocarbons and through the GC for methane contribution, an indication of burner VOC combustion efficiency was calculated.

A Carle Model 211 Gas Chromatograph was used with the following column and conditions.

Chromosorb 102 80/100 on 6' x 1/8" S.S. followed by Poropak Q 50/80 on 3' x 1/8" S.S.; column temperature 125°C; flow rate - 20 cc/min.

DATA REDUCTION, VALIDATION, AND REPORTING FORMAT

Data can be classified as either discrete data points such as velocities, pressures, temperatures, meter readings, moisture determinations, Orsat results, and gas chromatography samples, or as continuous data such as total hydrocarbon analyses produced with the FID. Data reduction procedures for discrete data points are listed below:

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Parameter	Data Reduction Procedures or Reference
Velocity and Volumetric Flow Rate	EPA Method 2
Moisture Content	EPA Method 4
Dry Molecular Weight	EPA Method 3
Methane Concentration in Burner Exhaust as Determined by Gas Chromatography on Discrete Samples	CH_4 peak identified by retention time determined in calibration. Concentration determined by peak height as a ratio of calibration gas peak height for known concentrations. This was done on an integrated bag sample taken over the period of the run.
Total Hydrocarbons in Burner Exhaust Using FID Analyzer	Analyses were done on integrated bag samples. Concentrations were calculated by calibration of chart prepared during calibration of analyzer which relates net chart percent of scale to concentration of calibration gas.
Non-Methane Hydrocarbons in Burner Exhaust	Obtained from difference between total hydrocarbons and methane.

An FID analyzer was used in the continuous mode on the burner inlet. This was done to avoid possible wall losses that might result from use of a Tedlar bag sampler at high inlet VOC concentrations. Also, the continuous data provided information on the variation of inlet concentrations. A time-weighted percent of scale was obtained by a manual equal area technique similar to that used in reducing ambient air quality data. Any range change was taken into account, although the percent of scale was corrected to concentration using percent of scale versus concentration plots obtained during calibration. It was not believed necessary, however, to change range unless the paint line stopped during the sample runs. All of the burner inlet hydrocarbons were assumed to be nonmethane.

Data were validated by checking for completeness of all data required for each run, by running calibration and zero checks for each run on all hydrocarbon and Orsat data, and by independent review of all calculation data entries.

QUALITY CONTROL PHILOSOPHY AND APPROACH

Quality assurance objectives for each major measurement parameter are shown in Table 4.

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TABLE 4. QUALITY ASSURANCE OBJECTIVES

Measured Parameter	Reference	Experimental Condition	Precision Standard Deviation	Accuracy*
Stack Gas Flow Rate	EPA Ref. Methods 2, 3,4	1) spray booth bypass vent at ambient temp. 2) Burner vent at about 500°F	± 3%	± 7%
Total VOC as CH_4 by FID		(See above) Expected vol. conc. from <100 ppm to 3000 ppm	± 2%	± 5%
CH_4 by Gas Chromato-graphy		(See above)	± 2%	± 5%

* Percent of true value

Calibration Procedures

The following calibration procedures were used to provide quality assurance.

Parameter	Method
Stack Gas Velocity by Pitot Tube	As specified in Section 3.1.2 of EPA document 600/4-77-027b, "Quality Assurance for Air Pollution Measurement Systems, Volume III, Stationary Source Specific Methods."
Sample Volume for Moisture Content Using Dry Gas Meter	As specified in Section 3.3.2 of EPA-600/4-77-027b.
CO_2 and O_2 by Orsat	As specified in Section 3.2.2 of EPA-600/4-77-027b.
Total VOC by FID	Compressed gas cylinder of xylene in air at 1000 ppm, prepared and certified by a calibration gas supply firm authorized to prepare certified reference materials.

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Parameter	Method
Methane by Gas Chromatography	Compressed gas cylinder of methane in air at 100 ppm prepared and certified by calibration gas supply firm.

Internal Quality Control Checks

Project participants had available a number of techniques and standards to impose internal quality control. These included replicates, spiked samples, split samples, control charts, blanks, internal standards, zero and span gases, quality control samples, surrogate samples, calibration standards and devices, and reagent checks. Many of these are applicable only to long-term sampling (control charts) or to wet chemical laboratory analyses (reagent checks). Therefore, only a selected number of the above techniques were applicable to this project. The following table was prepared to show the internal quality control checks that were applied.

Measurement	Quality Control Check
Stack Velocity by Pitot Tube	1) Calibrate with standard pitot tube. 2) Check for proper geometry. 3) Leak test draft gages.
Stack Temperature	Calibrate all thermometers and thermocouples against ASTM referenced thermometers in various constant temperature baths, e.g. ice, boiling water, boiling cooking oil.
Gas Meters	Calibrate against wet test meter and leak test sampling system (water content).
CO_2 and O_2 by Orsat	1) Use fresh reagents. 2) Leak test all apparatus including integrated sample bag. 3) Check against atmospheric oxygen. Should be between 20.1% and 21.5%.
Total Hydrocarbons by Flame Ionization	1) Check for stable background signal. 2) Conduct pre- and post-test span and zero checks on cylinder gases. 3) Leak test sample system.
Methane by Gas Chromatography	1) Introduce calibration standard prior to each sample introduction. 2) Check for stable baseline. 3) Check for proper retention time on CH_4 peak. 4) Run duplicates from each integrated bag sample.

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All flow and temperature measuring devices were calibrated before and after the field testing. The short duration of the testing (a few days) did not necessitate onsite calibration. The GC and total VOC analyzers were calibrated before each test condition. The OVA type portable hydrocarbon analyzer was also calibrated onsite.

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Preventive Maintenance

Since this was a short-term test program the emphasis, therefore, was to ensure that all equipment was in working order prior to transport to the site and after completion of the testing.

Procedures to Assess Data Precision, Accuracy and Completeness

Precision and accuracy of VOC measurements were assessed initially by running five replicate samples of VOC standards on both the FID detection and on the gas chromatograph. Sample precision was estimated from three replicate runs on the gas chromatography samples and by post-run calibration of both analyzers.

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Corrective Action

Preliminary sampling data and results of postsampling checks were examined after each sample run. Equipment was also examined physically. Where evidence of malfunction or operation error was found, the cause was evaluated and corrected prior to the next run. Runs which exceeded acceptability limits on precision checks were flagged and rerun.

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SECTION 5

RESULTS

Testing was started on December 13, 1982 after a preliminary investigation of the test site, and continued through Friday, December 18, 1982.

TEST PLAN MODIFICATIONS

The procedures as presented in the test plan could not be carried out in the field. The downturn in the economy had impacted the farm implement and heavy machinery industry severely. As a result, due to large inventories, Davenport production had been dramatically reduced. The effect of this production curtailment on the test program was that it would no longer be practical to accumulate quantities of parts requiring similar paint and schedule their coating applications over 30-minute periods. In fact, during the entire test period, the paint spray booth operation was plagued with many interruptions due to lack of production quantities.

The unexpected inability to control part and paint inputs to the spray booth operation required reevaluation of the data gathering procedures. According to Deere personnel, during any continuous conveyor run, up to five different paint types could be used. Deere then supplied the solvent composition of each of the paints. Review of the solvent data indicated that in addition to xylene, the major constituent solvent, significant quantities of mineral spirits and aliphatic naphtha would be used. Therefore, the use of xylene as the FID reference gas for examination of the bleed stream was not considered appropriate. Instead, methane was used to establish a consistent reference for all data analysis.

The test plan was modified to reflect three important changes.

1. Production was no longer continuous; therefore, painting inside the booth was intermittent;

2. Decreased parts demand meant stockpiling of similar materials could not be accomplished; therefore, the paint type used in the booth at any given time could not be controlled; and

3. The primary solvent used in some of the paints was not xylene; therefore, use of xylene as a calibration gas was considered inappropriate.

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To overcome these difficulties, two modifications were made to the test plan:

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1. Pint samples of the two Deere and Company Valspar paints (green enamel and primer) were analyzed to characterize mineral spirit and aliphatic naphtha components; and

2. A data gathering form was devised to correlate the quantities of each paint used at the beginning and end of each test period, the painting activity inside the booth, and the time. The form is presented in Appendix B.

The paints employed in Booth 777 were physically located in drums and pots at three different locations throughout the plant. No scales or other precise measures of the amounts were available during the test period. The investigators therefore devised a level change procedure to indicate quantities consumed during the test. The level at the beginning and end of each test was measured using a "dip" stick. The inches of change were logged onto the data sheets. Drum physical dimensions and reported paint densities are presented in Appendix C, as well as the calculation procedure. Appendix D presents the data sheets for the five tests run using this procedure. The data are summarized in Tables 5 through 8.

BLEED STREAM MEASUREMENTS

Total Hydrocarbon Concentrations

The FID strip chart records from continuous monitoring in the bleed stream were reduced to nominal 15-minute average values. These reduced values were summarized and presented in the following five tables. To facilitate referencing between test runs, a data summary was presented in Table 9. The results in Table 9 do not include the results of Test 1. That test period consisted primarily of experimentation with the revised test procedures.

Flow Measurements

The flow rate through the 30 cm (12 inch) bleed stream duct was measured using an 8-point velocity traverse. Stack temperature was 294 K (70°F) and moisture content was 1.51 percent. Measured average exhaust gas volume was 28 m^3 [990 actual (951 dry standard)] cubic feet per minute.

RECIRCULATING DUCT MEASUREMENTS

One goal of the research was to measure the flow rate and total hydrocarbon composition of the recirculation system. Three blowers of identical size and model operate in three ducts, designated Southwest No. 2, North-central No. 3 and Southeast No. 6.

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TABLE 5. RESULTS OF TEST 2
December 15, 1982
Duration of Test: 1229 - 1340

Paint Type[1]	Number of Gun Minutes of Activity[2]	Time of Longest Activity	Level Change in Container (inches)	Quantity Utilized[1] (lbs)
P1 and P2	2	One minute maximum	1	3.4
D1	31	1318-1321 (gun #2) 1328-1331 (gun #1)	1	17.9
D2	9	One minute maximum	1.5	24.6
D3	6	One minute maximum	< .5	5
D4	80	1255-1306 (gun #1) 1257-1307 (gun #2)	4.5	66.4

[1] See Appendix C for paint code and quantity calculation
[2] Represents total minutes either gun in specific paint activity, total for two guns.

TABLE 6. RESULTS OF TEST 3
December 15, 1982
Duration of Test: 1430 - 1510

Paint Type[1]	Number of Gun Minutes of Activity[2]	Time of Longest Activity	Level Change in Container (inches)	Quantity Utilized[1] (lbs)
D1	5	1431-1434 (gun #2)	< .25	4
D2	1	One minute maximum	neg.	-
D4	39	1433-1442 (gun #1) 1435-1443 (gun #2)	2	29.5

[1] See Appendix C for paint code and quantity calculation
[2] Represents total minutes either gun in specific paint activity, total for two guns.

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TABLE 7. RESULTS OF TEST 4
December 16, 1982
Duration of Test: 0822 - 1037

Paint Type[1]	Number of Gun Minutes of Activity[2]	Time of Longest Activity	Level Change in Container (inches)	Quantity Utilized[1] (lbs)
D1	22	0838-0843 (gun #1)	2.25	40.2
D3	24	1024-1027 (gun #2)	1	14.1
D4	81	0841-0900 (gun #2)	4.5	66.4

1 See Appendix C for paint code and quantity calculation
2 Represents total minutes either gun in specific paint activity, total for two guns.

TABLE 8. RESULTS OF TEST 5
December 16, 1982
Duration of Test: 1310 - 1433

Paint Type[1]	Number of Gun Minutes of Activity[2]	Time of Longest Activity	Level Change in Container (inches)	Quantity Utilized[1] (lbs)
D1	9	Two minutes maximum	2.25	40.2
D3	4	1410-1413 (gun #2)	1	14.1
D4	29	1420-1428 (gun #2)	4.5	66.4

1 See Appendix C for paint code and quantity calculation
2 Represents total minutes either gun in specific paint activity, total for two guns.

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TABLE 9. BLEED STREAM CONCENTRATION SUMMARY

Test Number	Measurement Time[1]	Average Concentration (ppm) Total Hydrocarbons[2]	Xylene[3]
2	1225-1254	687	94
	1302-1344	1128	161
3	1420-1510	925	132
4	0818-0945	1400	200
	0945-1037	1029	147
5	1219-1315	1084	155
	1338-1436	1031	147
12/16/82	1454-1515	900	129
	1608-1632	2066	296
	1658-1917	846	121
12/17/82	0812-1138	994	142

1 The measurement times presented for specific test numbers typically extend beyond the elapsed times reported in the previous tables. The FID began monitoring the bleed stream prior to test commencement so that increases in concentration could be compared to initiation of activity. Therefore, these elapsed times will be longer.
2 Total measured as methane
3 Calculated based on calibration curves of response factors

Recirculation Air Flow Rate

The flow rate through the recirculating duct system was measured at a sampling port in the Southwest No. 2 duct. Measurements were taken at this one point and considered representative of the other two operating ducts. Justification for this assumption was provided through motor performance measurements taken by Deere and Company maintenance crews. Since all three blower motors are the identical model number, motor performance would be reflected through amperage draw. If amperages are similar, the motors and resultant generated flows were assumed to be operating at similar rates. Measurements of the three motors were:

Southwest No. 2: 21 amps
Northcentral No. 3: 23 amps
Southeast No. 6: 22 amps

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Based on these results, the system was considered balanced and measurements through Southwest #2 were considered to be representative of the other two ducts.

The Southwest #2 duct measured 88 by 81 cm (35 by 32 inches). A 25-point traverse (5 vertical by 5 horizontal matrix) was performed. Duct temperature was 292 K (66°F) giving a recirculating gas volume of 522 m^3 (18,434 dry standard cubic feet) per minute. This flow rate multiplied by three resulted in a calculated total recirculation rate of 1,566 m^3 (55,302 dscfm). The measured flow rate through the three ducts when moisture was included was 1,634 m^3 (57,684) acfm. This flow rate includes a moisture content of 2.47 percent.

Recirculation Air Hydrocarbon Concentrations

Sampling holes were drilled in each of the three recirculation ducts. Probes were inserted with heated lines running to an FID. Total hydrocarbon measurements ranged from a low value of 828 ppm to a high value of 2,750 ppm as methane (Table 10).

6-1/2"

TABLE 10. RECIRCULATION DUCT HYDROCARBON MEASUREMENTS

9-1/8"

Duct	Time of Measurement	Results THC	Results Xylene[1]
Southwest #2	12/16/82 1600-1624	1888	270
	12/16/82 1705-1713	1250	179
Northcentral #3	12/16/82 1626-1630	1750	250
	12/16/82 1719-1730	1600	228
	12/17/82 0816-0824	1850	-
Southeast #6	12/16/82 1632-1636	2750	393
	12/16/82 1749-1847	828	120
	12/16/82 1900-1908	990	142
	12/17/82 0829-0841	1450	-

[1] Calculated based on calibration curves of response factors.

BURNER EXHAUST MEASUREMENTS

Measurements of THC and VOC concentrations in the burner exhaust were made by taking integrated bag samples to permit analysis of total hydrocarbons, oxygen and carbon, and CO_2. A series of measurements were taken and compared to corresponding bleed stream values taken during the same time frame (Table 11).

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TABLE 11. BLEED STREAM AND BURNER EXHAUST COMPARISON ON DECEMBER 16, 1982

Bleed Stream				Burner Exhaust			
Time	THC (ppm)	O_2 (%)	CO_2 (%)	Time	THC (ppm)	O_2 (%)	CO_2 (%)
0825-0911	1260	21	NM	0826-0911[1]	1605	21	NM
0945-1013	875	18.2	1.8	0945-1013[1]	4690	17.7	1.8
1255-1302	1215	19.2	1.0	1255-1302[2]	4690	19.6	1.0
1420-1445	1045	19.6	0.3	1420-1445[2]	4690	20.0	0.8

NM Not measured
1 Burner No. 5
2 Burner No. 4

As information began to accumulate, it became clear that burner operations were not as expected. It became evident from the data that the burners were combusting neither the inlet bleed stream air nor all of the natural gas. Burner adjustments were made by plant engineers. To better demonstrate the effectiveness of the system, it was also decided, for the remaining tests, to exchange the integrated bag sampling strategy at the burner outlets for a probe, pump, and heated line system back to the FID. This equipment setup would allow for rapid switching between locations to establish burner VOC destruction. Results after the burner adjustments are presented in Table 12.

TABLE 12. BLEED STREAM AND BURNER EXHAUST COMPARISON ON DECEMBER 17, 1982

Bleed Stream				Burner Exhaust #5			
Time	THC (ppm)	O_2 (%)	CO_2 (%)	Time	THC (ppm)	O_2 (%)	CO_2 (%)
0841-0847	850	NM	NM	0847-0858**	5	NM	NM
0858-0908	200	NM	NM	0908-0919*	150	NM	NM
0919-0921	125	NM	NM	0958-1004**	0	NM	NM
0947-0958	1000	NM	NM	1010-1011**[1]	0	NM	NM
1004-1010	1150	NM	NM	1027-1036**	0	NM	NM
1011-1027	1250	NM	NM	1042-1050**	0	1.0	11
1036-1042	1300	NM	NM	1050-1102*	0	12	6
1102-1112	1000	21	NM	1112-1122*	0	11.2	5.8
1122-1127	950	21	NM	1127-1135*	0	10.8	6.0
1135-1138	1200	21	NM				

NM - Not Measured, * Low Fire, ** High Fire
1 Short sampling time the result of flame out in the high fire mode.

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The use of the FID to demonstrate burner combustion efficiency required a rapid switching procedure. The sampling team was concerned that the burner exhaust measurements on the FID be indicative of operations during the period in question. The line ran over 15 m (50 feet) and contained a significant volume. Using a span gas of known concentration introduced into the burner probe, it was determined that the sampling delay time from the burner exhaust to the FID ranged from 40 to 60 seconds. Therefore, to assure representative results after each switching between bleed stream and Burner No. 5 exhaust, the sampling time was a minimum of 5 minutes.

Comparison of Table 12 with Table 11 indicates that once the burners were properly adjusted, destruction of the bleed stream hydrocarbons and the natural gas fuel approached 100 percent. This value of zero presented in Table 12 was measured on a 0 to 5000 ppm instrument scale. Pre- and post-run instrument calibrations using a 110 ppm hydrocarbon gas produced readings of 2.1 percent of chart and 2.3 percent of chart respectively (2.2 percent of a 5000 ppm chart represents a 110 ppm concentration). Therefore, the accuracy of any reading (including zero) can be expected to be 0.2 percent of scale, or in the case of a 0 to 5000 ppm scale, 10 ppm.

6-1/2"

GAS CHROMATOGRAPHY RESULTS

Bag samples of the bleed stream and burner exhausts were collected and analyzed by gas chromatography. The bleed stream bag sample was analyzed for the presence of xylene. The large fractions of unknown THC found in the analyses (Table 13) demonstrated the significant use of mineral spirit and aliphatic naphtha-based solvents.

The initial burner exhaust gas chromatography results confirmed the suspicions raised by the measurements presented in Table 11. It was evident from the quantities of methane and unknown THC detected by the gas chromatograph that neither the natural gas nor bleed stream hydrocarbons were combusted by the burners.

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TABLE 13. GAS CHROMATOGRAPHY RESULTS
(Values presented in ppm)

Source	Date and Time		m-Xylene	Methane	Unknowns[1]
Bleed stream	12/15/82	1225-1254	22		78
Bleed stream	12/15/82	1303-1344	40		135
Bleed stream	12/15/82	1422-1510	23		93
Burner #5 low fire	12/16/82	0826-0911		330	1414
Burner #5 high fire	12/16/82	1005-1013		3483	1430
Burner #4 low fire	12/16/82	1255-1302		3134	1514
Burner #4 high fire	12/16/82	1302-1344		3369	1338
Bleed stream	12/16/82	0826-0911	41		102
Bleed stream	12/16/82	0945-1013	21		73
Bleed stream	12/16/82	1255-1302	20		132
Bleed stream	12/16/82	1420-1445	27		99

[1] When measurements are reported as m-Xylene, unknowns are also reported as m-Xylene. When measurements are reported as methane, unknowns are also reported as methane.

CURING OVEN INLET

As discussed in the process description, paint spray booth No. 777 was not a totally enclosed system. Parts which had been painted travelled by overhead conveyor directly into the paint curing oven through a large opening in the east wall of the booth. This opening in one wall of the spray booth provided an alternate path by which booth air and volatile organic compounds could leave the recirculating system. A hand-held anemometer was used to traverse the opening into the curing oven to obtain velocity measurements (Figure 5). No parts were moving along the conveyor at the time of the measurement (1540 on 12/15/82). However, the recirculation system was operational.

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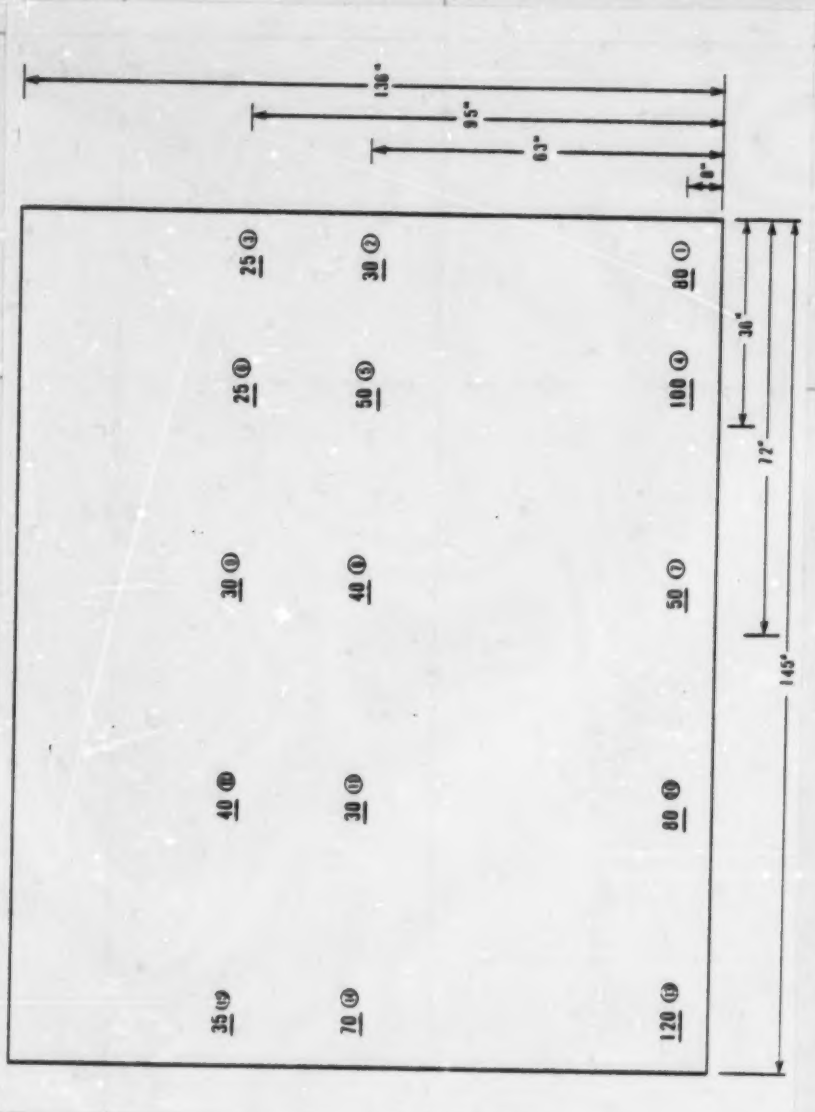

Figure 5. Velocity Profile at Opening Between Cure Oven and Paint Spray Booth 777 (Values shown are in feet per minute)

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The cross-sectional area of the opening was 12.7 m^2 (137 ft^2). Summing the 15 measured speeds and dividing yielded an average velocity over the face of the entrance of 16.4 m (53.7 ft) per minute. The volume flow rate was calculated as 208 m^3 (7,357 ft^3) per minute.

IN-PLANT HYDROCARBON SURVEY

The wash water circulating in the bottom portion of the paint spray booth served primarily as a capture system for particulate matter and a portion of the hydrocarbons generated in the painting process. This water was collected in a below-ground collection pit before recirculation to the spray booth. Measurement of THC concentrations both in the collection pit and at selected above-ground stations in the vicinity of the paint spray booth were taken (locations of stations are shown in Figure 6). If the measured concentrations in the pit were 200 percent or greater of the background values, it was considered to be an indication that the wash water was removing a large portion of the solvent THC and the collection pit was a potentially significant source of THC emissions.

The determination of significance was done by utilizing a portable hydrocarbon analyzer, the Foxboro Organic Vapor Analyzer (OVA) Model 108.

Paint Spray Booth 777 Proximity Survey

A survey in and around Spray Booth 777 was taken on two occasions during the test program. The measurements presented in Table 14 were taken at the sampling stations shown in Figure 6.

TABLE 14. BACKGROUND HYDROCARBON MEASUREMENTS
(Values are ppm as methane)
December 17, 1982

Station	Background at 0750	Background at 1045
1	23	48
2	62	40
3	78	100
4	30 (frequent spikes to 120)	10
5	13	10
6	13	10
7	15	8
8	13	11
9	120	130
10	120	
11	N.M.	150
12	N.M.	250
13	N.M.	210
14	N.M.	230

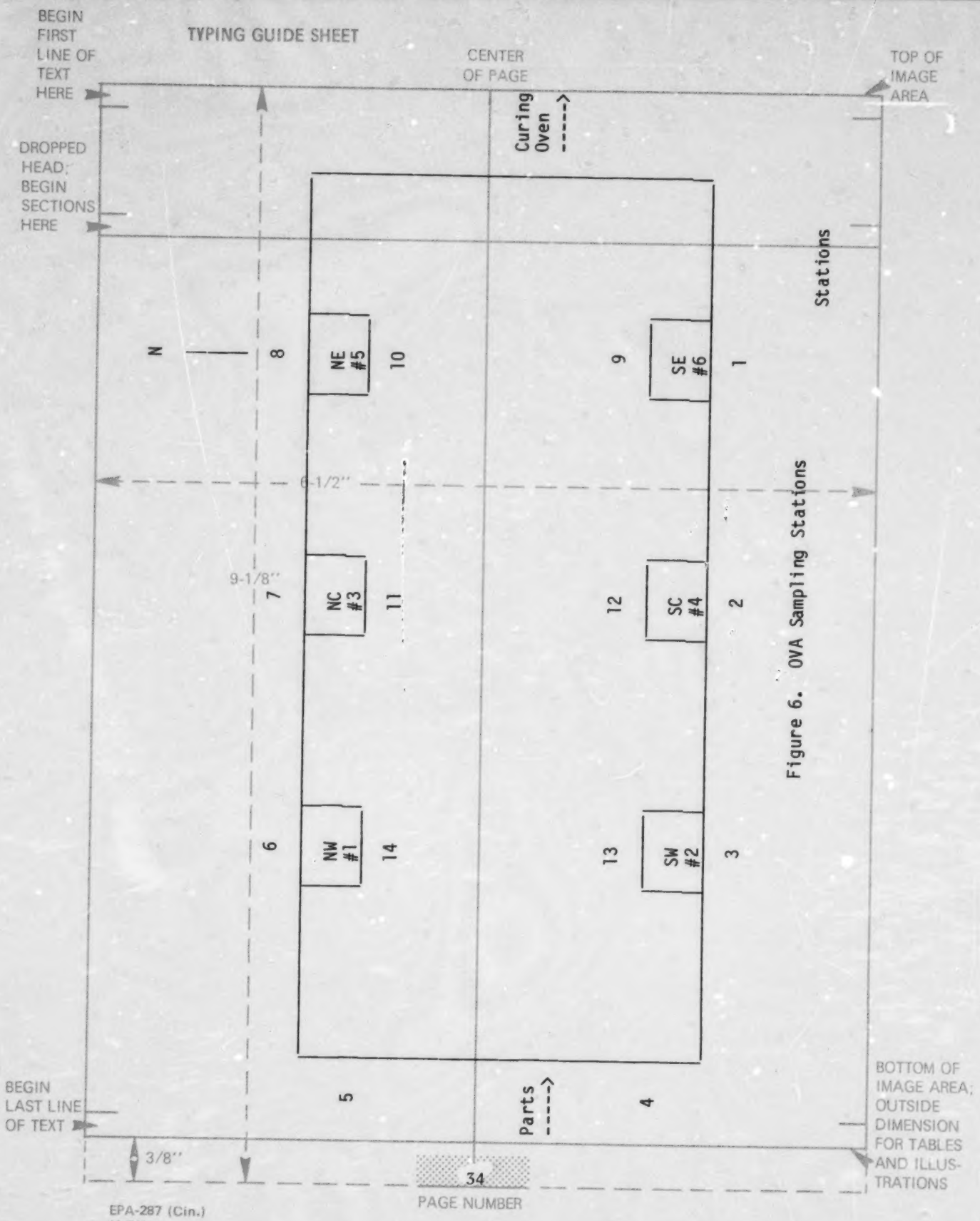

Figure 6. OVA Sampling Stations

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Waste Water Collection Pit

The waste water collection pit was below ground just to the northeast of paint spray booth 777. The pit measured approximately 24 feet by 30 feet with an above-water level height of 12 feet. Four measurements using the OVA-108 were made in the pit on 12/17/82. All measurements were taken 2 feet above liquid surface. Results were as follows:

Sample Location 1 - 25 ppm (as methane)

Sample Location 2 - 75 ppm

Sample Location 3 - 50 ppm

Sample Location 4 - 40 ppm

Values observed were considered not significantly different from those found on the sheltered southern side of the booth.

QUALITY ASSURANCE

Response Factor Determination

Instruments used for this project were calibrated using methane in air contained in compressed gas cylinders. Data from these instruments were then reported as methane equivalents; in order to determine the amount of xylene (the predominant solvent in the gas stream) that was present one can use a correction factor or response factor to convert the data from methane equivalents to xylene. The response factor can either be a published value, or determined empirically. The latter was performed by first calibrating the instrument with methane and then introducing a known concentration of xylene. The difference in instrument response between the two gases was then calculated as a ratio and reported as the response factor. Since each instrument generally responds differently to the same calibration gas, a response factor was determined for each analyzer.

For example, the Scott Model 215 response factor was determined by first calibrating the instrument with methane. A known concentration of 1002 ppm methane in air was used, the instrument was operated on the zero-10,000 ppm scale. The instrument zero and span pots were adjusted to obtain an analyzer output reading of 1002 ppm. A test atmosphere of 1145 ppm of xylene was prepared in a Tedlar bag and introduced to the analyzer. The analyzer output was 14.96 ppm/chart division as compared to 104.4 ppm/chart division for methane, therefore, the ratio of methane to xylene was 0.143. This could also be interpreted to mean that the relative response of the instrument to xylene is less than that for methane. The values that were reported herein have been corrected using this response factor.

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Methane Calibration of Total Hydrocarbon Analyzer

Prior to collecting any data each instrument was multipoint calibrated with various concentrations of methane calibration gas. The instrument full scale response was determined using zero air (containing no hydrocarbons) and a 75% of full scale calibration gas. Once the full scale response was established, additional calibration gases were used at nominal concentrations of 20%, 40%, 60% of full scale (refer to Appendix E for calibration gas certifications). The purpose of a multipoint calibration was to determine instrument linearity. After the calibration gases had been introduced to the analyzer, a linear regression was performed using the actual instrument response versus theoretical response. Acceptable instrument linearity was a correlation coefficient between 0.9998 and 1.0002.

After each of the sample runs, the instrument calibration was re-verified using a span gas of 110 ppm. The instrument performance results are presented in Table 15. These values were compared to instrument precision values summarized in Table 4.

Leak Checks

The sample delivery system was leak checked at the beginning and conclusion of each sample day. Leak checks were also conducted when any maintenance was performed on the sample delivery system during the sampling runs. Leak checks were performed using two methods. The first method included the delivery of span gas from the sample probe through the entire sample delivery system to the analyzer. If the system was found to be leak-free, instrument response was within ± 1% for span gas delivered through the entire system versus delivery of span gas at the analyzer inlet. Another method was also used to verify the performance of the sample delivery system. One atmosphere of vacuum was pulled on the system. If the system held the vacuum for one minute, it was considered to be leak free. A loss of 0.1 PSI or less was the established criterion for a leak-free system.

Gas Chromatography

All sample gathering in the field was performed under strict chain-of-custody procedures. Each bag sample gathered for gas chromatography (GC) analysis was tagged in the field. The tag identified the stream measured and the time duration involved. Each sample was recorded by the tag parameters on the GC record for easy future reference.

Pre- and post-calibration standards were used whenever analysis changed from methane to xylene. Duplicates of each integrated bag sample were run to assure accuracy.

Calibration Gas Certification

All primary calibration gases used in the field or in the laboratory were purchased from a specialty gas supplier. The calibration gases were purchased in compressed gas cylinders certified accurate to ± 20%.

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TABLE 15. QUALITY ASSURANCE DATA

Date	Analyzer Model #	Analyzer Range	Pre-Calibration Span Input Conc. (ppm)	Pre-Calibration Span Output % Chart	Pre-Calibration Span Output Conc. (ppm)	Analyzer Range	Post-Calibration Span Input Conc. (ppm)	Post-Calibration Span Output % Chart	Post-Calibration Span Output Conc. (ppm)	Precision Standard Deviation	Accuracy ± ppm	Percent Error
12/15/82	Scott 215	0-1 K f/s	110 ppm CH_4	11.0%	110	0-1 K						
		0-5 K f/s	110 ppm CH_4	2.1%	105	0-5 K	110 ppm CH_4	2.1%	105	2.5	± 5 ppm	0
12/16/82	Scott 215	0-5 K f/s	110 ppm CH_4	2.3%	115	0-5 K	110 ppm CH_4	2.3%	115	2.5	± 5 ppm	0
12/17/82	Scott 215	0-5 K f/s	110 ppm CH_4	2.1%	105	0-5 K	110 ppm CH_4	2.3%	115	3.5	± 50 ppm	10
12/15/82	Tracor 550	G-C (FID)	1040 ppm xylene		1040	G-C (FID)	1040 ppm xylene		1028	5.2	± 13 ppm	-1.2
12/16/82	Tracor 550	G-C (FID)	1040 ppm xylene		1040	G-C (FID)	1040 ppm xylene		1029	5.2	± 13 ppm	1
12/16/82	Tracor 550	G-C (FID)	110 ppm CH_4		110	G-C (FID)	110 ppm CH_4		108.5	0.7	± 1.5 ppm	-1.4

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SECTION 6

SYSTEM PERFORMANCE

Standard procedure in the preparation of technical reports for EPA is to present the data in metric units with the English equivalent in parentheses. This is not always consistent with current industry convention. To enable the reader to better understand several involved calculations presented in this chapter, the values are presented and evaluated using the English units of measurement and payment as supplied by the industry.

Deere and Company modified a previous once-through paint spray booth air design to recirculate the major fraction of the inlet air. Conceptual before and after diagrams of the system is presented in Figures 7 and 8. The recirculation rate was determined to be 88.7 percent. The ability of this recirculating system to handle frequent color changes eliminated a suspected disadvantage of this type of operation over once-through designs.

RECIRCULATING SYSTEM PERFORMANCE

The calculated recirculation rate of the system was based upon measurements in one duct and extrapolation through similar motor current draw to the other two operating ducts. The recirculation rate totalled to 1,566 m^3 (55,302 dscfm) with a moisture content of 2.47 percent (1,634 m^3 [57,684 acfm]).

When calculating the recirculation rate as a percent of the total system activity, losses through all exhaust points had to be included. The important stream to be considered is the loss through the curing oven. The second exhaust stream, the bleed stream, is accounted for based on the selected sampling point in the recirculating system. Recirculation as a percent of total system flow was, therefore, determined to be:

$$\frac{57{,}684 \text{ acfm}}{[57{,}684 + 7{,}357 \text{ (curing oven)}] \text{ acfm}} = 88.7 \text{ percent}$$

OPERATING SCENARIO USED AT DAVENPORT

The practice at the Davenport facility of painting different parts with different colors in the same booth within a distance of as little as 6.1 m (20 feet) demonstrated a wide flexibility of booth and recirculation potential operational applications. The downdraft air flow evacuated the immediate volumes so rapidly and thoroughly that product quality was not adversely

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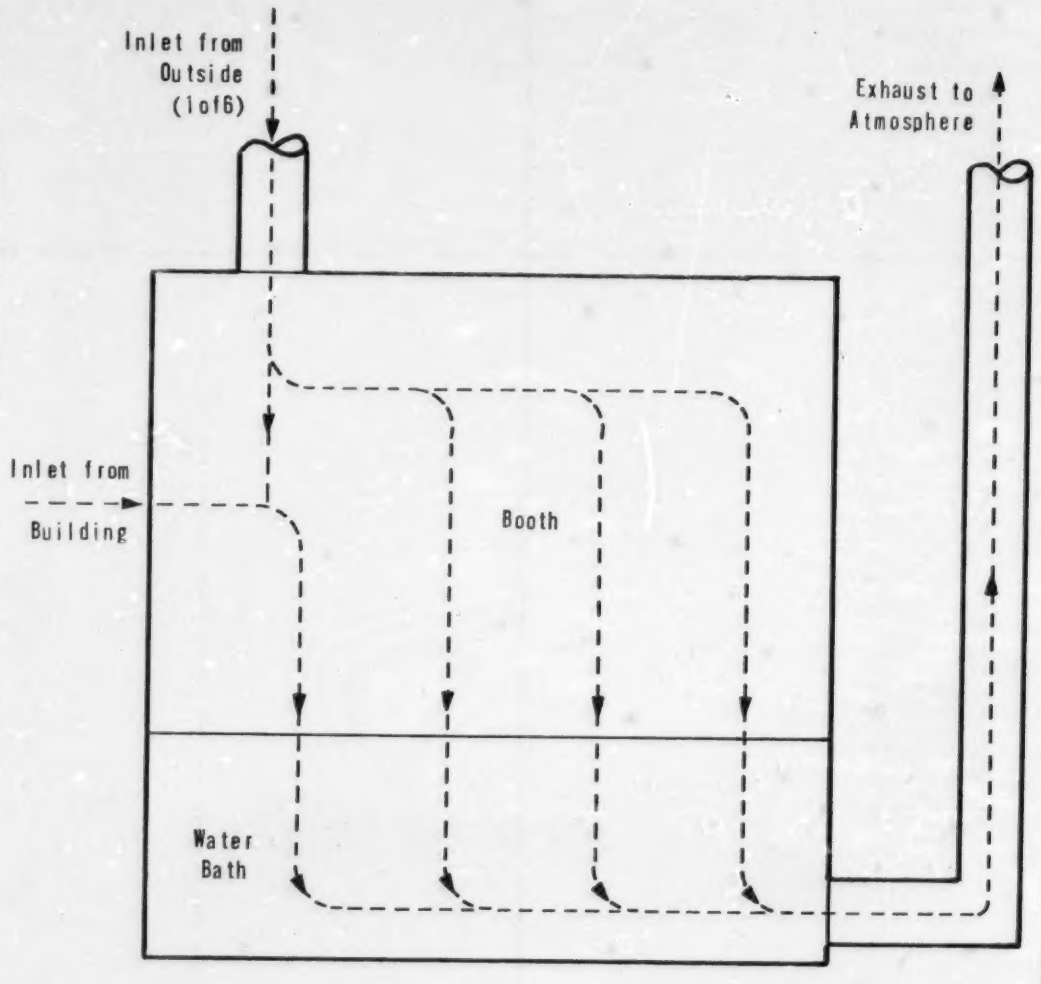

Figure 7. Davenport Works Paint Spray Booth 777 Before Recirculation (Generalized Flow)

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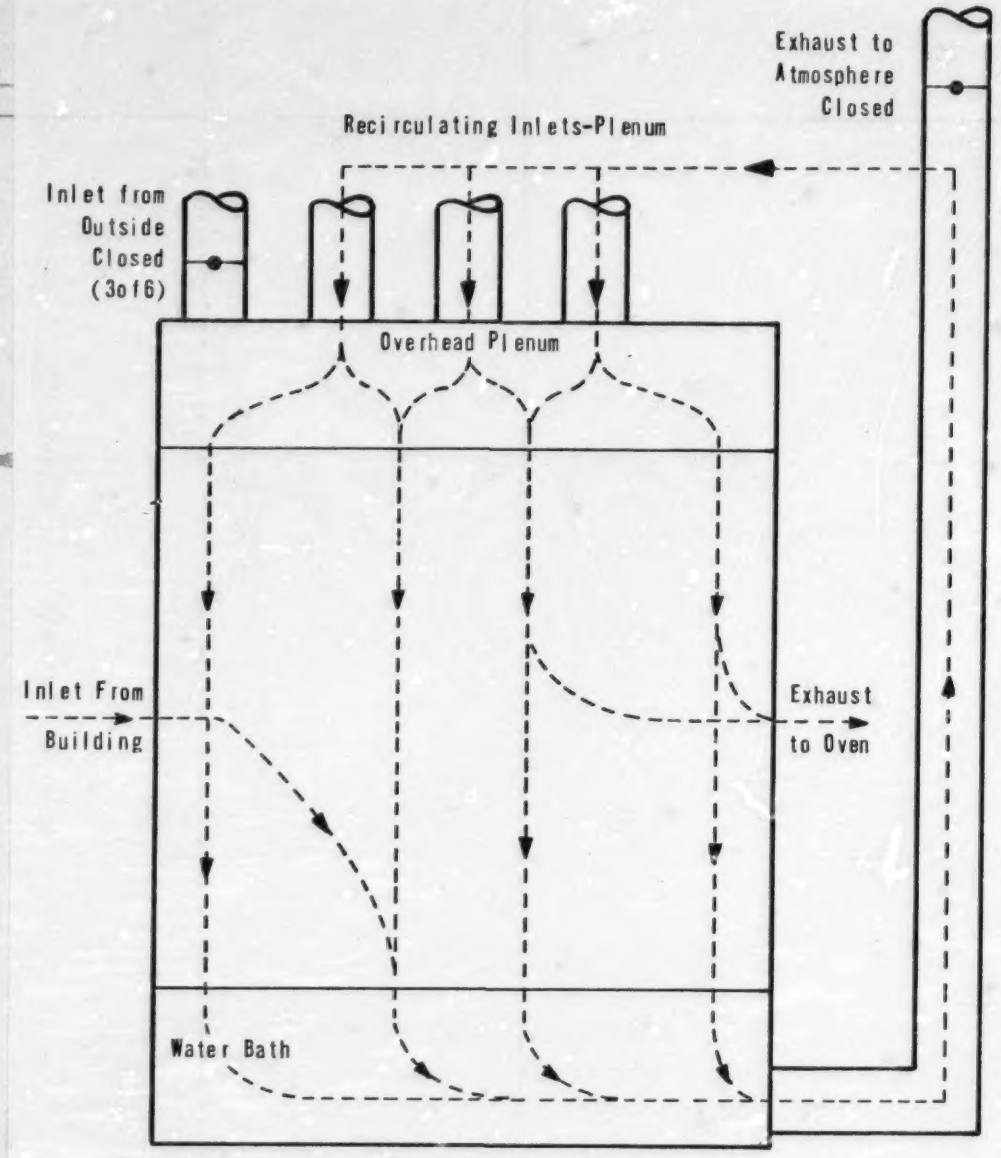

Figure 8. Davenport Works Paint Spray Booth 777
After Recirculation (Generalized Flow)

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affected. Also, the type of applicator did not appear to affect booth performance. Use of both electrostatic spray guns and air atomization guns were observed. In each instance, frequent color changes were accomplished without apparent negative impact.

This ability to accomplish color switching in a spray booth with recirculation had been an initial concern. The Deere and Company booth in Davenport, Iowa demonstrated that color switching in a recirculating environment could be performed even when periodic air atomization applications were included. Therefore, applications where once-through systems were considered a necessity due to the need for booth color switching can consider a recirculation option.

BURNER PERFORMANCE

The performance of the high and low burner system at the Davenport facility demonstrated the need for systematic operation and maintenance practices. Based on analyses during the early testing period it was evident that bleed stream hydrocarbon concentrations were not being destroyed in the burner system. In fact, the natural gas feeding the burner flame was not igniting, resulting in an actual increase in total hydrocarbons between burner inlet and outlet due to uncontrolled natural gas.

The dramatic reversal of system performance as demonstrated in the measurements taken on the last day showed the effectiveness of ducting the bleed stream from the recirculation system to some type of control. Once the burners were properly adjusted, approximately 100 percent of the hydrocarbons in the bleed stream from the spray booth were destroyed as shown in Table 12.

OPERATIONAL FACTORS

The Davenport evaluation demonstrated that under a given set of operational conditions, a balance of inlet and outlet flows could be established that allowed for recirculation of 90 percent of the booth air without creating a potential worker exposure or explosion problem. The recirculation system has a great deal of flexibility that must be considered when examining its applicability to other situations. Each combination of flow capabilities, levels of painting activity, and available or considered air pollution control systems will establish optimum balances of flow and VOC concentration. In each instance, it is important that the VOC concentration be carefully monitored to assure that worker exposure and potential for explosion are considered and sufficient safety margins integrated into the design.

VOLATILE ORGANIC CARBON FLOW STREAM QUANTIFICATION

A number of factors can influence the point of emission of VOCs present in the paint solvent, including transfer efficiencies. Table 1 demonstrated

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the variations in transfer efficiencies that could result from parts characteristics and the method of paint application. Early in this study it was concluded that the purpose was not to calculate transfer efficiencies or emissions associated with part drying. The important goal of the study was to evaluate the system's ability to recirculate the booth air and draw off a manageable volume which could be economically controlled while not allowing VOC concentrations to reach dangerous levels.

To characterize the measured heterogeneous concentrations required an assumption of hydrocarbon molecular weight. Obviously, the assumption of molecular weight per carbon number was influenced not only by the length of carbon chain, but also by structure and functional groups present.

In the case where all solvents present are pure hydrocarbons, it is assumed that the molecular weight/carbon number is approximately 14. The conversion of ppm C values to gravimetric concentration (mg/m^3) is calculated as follows:

$$\frac{\text{ppm C} \times 14 \times 273}{22.4 \times (T+273)} = \frac{171\ (\text{ppm C})}{(T+273)}\ , \ (mg/m^3)$$

where T = stack temperature, degrees centigrade.

Using the level difference procedure described in Appendix C to quantify paint consumption, four tests were run to determine bleed stream concentration (Tables 5-9). Using data taken from Appendix A, the quantities of solvent could also be calculated. These values for each test are presented in Table 16.

Examination of the wash water sump reported in Section 5 concluded that there is negligible entrainment of VOC in this water. Therefore, since the booth itself is under negative pressure, the only exit sources for the VOC other than on the part are into the curing oven exhaust air, or through the recirculation system into the bleed stream.

Cure Oven. Table 14 indicated the horizontal VOC concentration in the booth. These measurements reached a peak value of 210 to 250 ppm when measured with an OVA-108. Two comments must be made concerning these values.

- Measurements were not taken at the expected point of maximum concentration, the point where the parts enter the oven
- Measurements were taken using an instrument different from FID with different response characteristics

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TABLE 16. SOLVENT USAGE IN PAINT MONITORING TESTS

Test #	Paints Used	Calculated Quantities (lb)	Solvent Content (wt. %)	Solvent Quantities (lb)
2	P1	3.4	53.8	1.8
	D1	17.9	29.0	5.2
	D2	24.6	45.0	11.1
	D3	5.0	57.0	2.9
	D4	66.4	42.9	28.5
Subtotal				49.5
3	D1	4.0	29.0	1.2
	D2	-	45.0	-
	D4	29.5	42.9	12.7
Subtotal				13.9
4	D1	40.2	29.0	11.7
	D3	14.1	57.0	8.0
	D4	66.4	42.9	28.5
Subtotal				48.2
5	D1	40.2	29.0	11.7
	D3	14.1	57.0	8.0
	D4	66.4	42.9	28.5
Subtotal				48.2

6-1/2"
9-1/8"

It was expected that concentration values entering the oven would be between the OVA value and the bleed stream concentration. For purposes of this review, the concentration of 500 ppm was used. This combination of concentration and flow rate into the oven yielded a constant mass rate in this direction for all tests of:

$$\frac{(171)(500\ ppm)}{294\ K} = 291\ mg/m^3$$

$$\frac{(291\ mg/m^3)\ (0.02832\ m^3/ft^3)\ (7{,}357\ ft^3/min)}{(453{,}600\ mg/lb)} = 0.13\ lb\ VOC/min$$

Bleed Stream. Using Table 9, time weighted bleed stream concentrations were developed and presented in Table 17. Also included is the corresponding mass per unit volume value based on the assumed relationship and a temperature of 294 K (70°F). The last column is a VOC loss on a unit time basis based on the measured bleed stream flow rate of 28 m^3 (990 ft^3) per minute.

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TABLE 17. BLEED STREAM CALCULATIONS

Test No.	Time Weighted Bleed Stream (ppm)	Mass/Volume (mg/m^3)	VOC Loss (lb/min)
2	948	551	0.034
3	925	538	0.033
4	1261	733	0.045
5	1057	615	0.038

Note: Information from Deere and Company indicates that % LEL has not exceeded 3% and most of the time was closer to 1%. Assuming the material to be naphtha, these measured values represent 2% of LEL, values that are consistent with instrument ranges.

6-1/2"

These measurements and calculations indicated that the majority of the VOC present in the inlet paint solvents did not appear in the bleed stream, paint sludge or water. When the combined bleed stream and curing oven VOC quantities were compared to the inlet paint solvent values (Table 18), it was shown that between 25 and 50 percent of the inlet solvent was emitted in the paint spray booth. The remainder of the solvent is still on the parts and is emitted downstream in the curing oven.

This study indicated that it was possible to successfully combust the VOC present in the bleed stream. If this bleed stream flow and/or VOC concentration can be increased the controllable percentage of solvent will also increase.

TABLE 18. SOLVENT LOSS COMPARISONS

Test	Duration (min)	Total Solvent Used (lb) (Table 16)	Spray Booth Emissions (lbs) To Oven	To Bleed Stream	Total	Percent of sprayed Total Solvent
2	71	49.5	9.2	2.4	11.6	23.4
3	37	13.9	4.9	1.3	6.2	44.6
4	135	48.2	17.9	6.1	23.7	49.2
5	83	48.2	10.8	3.2	14.0	29.0

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ENERGY IMPACTS

The major impact of the recirculating air paint spray booth concept is reduced emissions volume from the spray booth and reduced natural gas consumption for heating make-up air. As the volume of exhaust gases from the spray booth are decreased due to recirculation, the potential cost of VOC control of the booth emissions stream and of heating booth make-up air will be decreased. Calculations used to estimate reduced energy costs have as their basis the recirculation rate of 1,566 m^3 (55,302 dscfm) (flows through the curing oven and the bleed stream are considered losses). Air lost through the spray booth must be replaced by colder external air which must be heated to spray booth demands.

Energy Costs Before Modification*

To determine the potential energy savings when using air recirculation, it is necessary to examine the situation before and after modification.

Before modification, the system consisted of a once-through design with an inlet flow rate of approximately 80,000* scfm. To calculate energy usage before modification the following conditions were assumed:

- internal building temperature: 70°F
- external average temperature during heating season: 35°F
- duration of heating season: 7 months (29 weeks)
- schedule of booth: 16 hours/day, 5 days/week
- 1982 natural gas costs in the Davenport area: \$0.408/therm equal to \$4.08/10^6 Btu.

Energy costs were calculated by using the following formula:

$$\text{Btu/hr required to heat air} = (\Delta T) \times \text{scfm} \times 1.08 \ \frac{\text{Btu} \cdot \text{min}}{°\text{F} \cdot \text{hr} \cdot \text{ft}^3}$$

where the value 1.08 was the product of the specific heat of air (0.24 Btu/lb/°F), the density of air at 70°F (0.075 lb/ft^3) and the time factor (60 min/hr).

$$(0.24 \text{ Btu/lb/°F})(0.075 \text{ lb/ft}^3)(60 \text{ min/hr}) = 1.08 \ \frac{\text{Btu} \cdot \text{min}}{°\text{F} \cdot \text{hr} \cdot \text{ft}^3}$$

* These calculations were performed in the actual units of measure and payment so that readership understanding of the methodology would be enhanced.

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Energy costs before modification were:

$$(80 \times 10^3 \text{ scfm}) \left(1.08 \frac{\text{Btu}\cdot\text{min}}{^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^3}\right) (70\text{-}35^\circ\text{F}) = 3.02 \times 10^6 \text{ Btu/hr}$$

Annual energy costs during the heating season were:

$$(3.02 \times 10^6 \text{ Btu/hr})(16 \text{ hr/day})(5 \text{ day/week})(29 \text{ week/year})(\$4.08/10^6 \text{ Btu})$$

$$= \$28,586$$

Energy Costs After Modification

After modification, the net exhaust gas rate was the combination of flows traveling through the bleed stream and into the curing oven. The maximum flow rates through the two outlets were 1,500 scfm (bleed stream) and 7,350 scfm (curing oven) for a total of 250 scm (8,850 scf) per minute.

Energy costs after modification would be:

$$(8{,}850 \text{ scfm}) \left(1.08 \frac{\text{Btu}\cdot\text{min}}{^\circ\text{F}\cdot\text{hr}\cdot\text{ft}^3}\right) (70\text{-}35^\circ\text{F}) = 334{,}530 \text{ Btu/hr}$$

Annual energy costs during the heating season were:

$$(334{,}530 \text{ Btu/hr})(16 \text{ hr/day})(5 \text{ day/week})(29 \text{ week/year})(\$4.08/10^6 \text{ Btu})$$

$$= \$3,167$$

The annual savings was the difference between the two:

$28,586 - 3,167 = $25,419, or 89 percent.

ECONOMIC IMPACT OF TECHNOLOGY

Installation Costs

The cost of installation of the existing Davenport facility was supplied by Deere and Company. Costs were presented by two phases:

- Phase I involved the costs incurred to re-equip the spray booth atmosphere to allow recirculation
- Phase II involved the costs incurred to construct the bleed stream system and wash tank burners

Costs in 1981 dollars are presented in Table 19. Costs shown for the two phases were actual prices paid for services rendered by contractors. Total costs were $56,214. Engineering of the system was performed internally by Deere staff over a period of time. Manpower efforts for design of Phase I

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TABLE 19. INSTALLATION COSTS FOR PHASE I AND PHASE II AT DAVENPORT FACILITY

Effort	Cost
Phase I	
Ductwork Revisions	$19,866
LEL Analyzer, Gas Sampling System, and Recorder	7,473
CO Monitor, Span Gas, Audible Alarm	1,125
Painters Equipment (helmets, hoses, vortex heaters and coolers, etc.)	1,740
Helmet Cabinet	220
Electrical and Pneumatics	1,110
Miscellaneous unspecified-for expenditures	3,220
TOTAL	$34,754
Phase II	
Burners, Combustion Air Blower, and Associated Equipment	$ 8,690
Installation - Piping and Electrical	5,990
Hydrocarbon Stack Testing with Gas	2,580
Ductwork Revisions - Combustion Air Blower Inlet	1,940
Miscellaneous unspecified-for expenditures	2,260
TOTAL	$21,460

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and Phase II were estimated to be 120 hours. At an outside design firm rate of $50/hour, this corresponded to $6,000. Total installated costs were, therefore, $62,214.

Additional benefits could be obtained if a new recirculation system were designed instead of a retrofit. These benefits would include a reduced electrical equipment expenditure. A combined 15 percent savings over estimated retrofit costs could be realized due to reduced high voltage units, wires, motor house and other sheet metal and electrical substation requirements.

Operating Costs

Operating costs outside of energy expenditures would be replacement costs. To date, Deere and Company have not incurred any equipment replacement costs. Booth ceiling filters were replaced approximately three times per year at a cost of $300/yr. This rate of replacement is not considered significantly different from normal booths.

Control Options

The conversion of the booth exhaust system to a bleed stream with an exhaust volume of under 2,000 cfm presented the possibility to consider various control options. Deere and Company selected a novel incineration approach that included use of a nearby water heater burner system.

The following factors in the recirculation system design contribute to make this concept more attractive than would normally be expected for a once-through system. These factors include:

- reduced flow
- reduced energy requirements due to reduced flow
- reduced equipment size requirements
- increased VOC concentration

With reduced air flows, control equipment installations may be more viable. Control options such as incineration or carbon adsorption and incineration would be much less expensive.

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SECTION 6

POTENTIAL ALTERNATE CONTROL APPLICATIONS FOR THE RECIRCULATION TECHNOLOGY EXHAUST STREAM

The Deere and Company study results indicated that it was possible to recirculate significant quantities of booth air without affecting product quality or worker safety. Balance on the spray booth VOC concentration was maintained by bleeding off a small portion of the recirculating air. With proper spray booth design, this bleed stream could constitute the only exhaust stream from the system. This exhaust volume, being significantly lower than the exhaust volumes generated in a once-through system, has available a number of alternatives for VOC control.

The Davenport design includes an attached flash-off tunnel. To keep heated air generated in the curing oven from moving down the tunnel and into the paint spray booth, the recirculation modification design included an adjustment to the curing oven blower that created a negative pressure in the flashoff tunnel. As a result, a flow was induced out of the booth into the flashoff tunnel. This flow was measured to be approximately 210 m^3 (7,360 ft^3) per minute. The study indicates that when this value is combined with the bleed stream flows, it is possible to maintain an acceptable internal VOC concentration in a 2,260 m^3 (80,000 ft^3) per minute paint spray booth by drawing off slightly over 230 m^3 (8,000 ft^3) per minute or only 10 percent of the original exhaust volume.

The installation and operational cost savings of a 230 m^3 per minute VOC control strategy as opposed to a 2,260 m^3 per minute system are substantial. Additionally, the options as to type of VOC control strategy for the paint spray booth also expand. Deere and Company has selected to combust the solvent-laden bleed stream in two natural gas burners serving a nearby heated water bath. This is not, however, the only option available. A direct-fired incinerator would serve the same purpose as the natural gas burners. A reduced volume also makes practical consideration of alternatives such as carbon adsorption. Another option that can be considered is the use of the bleed stream air as combustion air for the curing oven. The feasibility of reducing the emissions volume from a spray booth as demonstrated by the Deere installation has made the control of spray booth more economical and practical.

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APPENDIX A

SOLVENT COMPOSITION OF PAINT USED AT DAVENPORT WORKS, 8 DECEMBER 1982

1. Fast dry green spray enamel	
Mineral spririts	
Aliphatic naphtha	17.98%
Cellosolve	10.16
Isopropanol	11.78
Xylol	7.18
Cellosolve acetate	3.02
Butyl cellosolve	1.10
Toluol	1.10
Butanol	.42
Aromatic naphtha (SC-100)	.02
Triethylamine	.79
	.22
2. Green lead and chromate free primer	
Mineral spirits	
Aliphatic naphtha	22.96%
Xylol	17.11
	2.81
3. Zinc chromate primer	
Xylene	
Heptane	62.00%
Mineral spirits	<5.00
	< .50
4. Scuff resistant black primer	
Xylene	
Toluene	37.00%
Ethylene glycol monoethyl ether acetate	<5.00
VM & P Naphtha	<5.00
Heavy aromatic naphtha (D-129)	7.00
Mineral spirits	7.00
Guaiacol (Special "C")	<5.00
	< .50
5. Scuff resistant black enamel	
Xylene	
Toluene	35.60%
VM & P Naphtha	1.87
Aromatic hydrocarbon (D-24)	8.16
Mineral spirits	3.51
Ethylene glycol monoethyl either acetate	< .50
	4.35

SOLVENT COMPOSITION OF PAINT USED AT DAVENPORT WORKS (Continued)

6. Olive yellow primer sealer	
Xylene	21.50%
VM & P Naphtha	13.00
Tetramethyl benzene	2.00
Mineral spirits	.50
Heptane	.50
7. Special Dupont red-orange truck color	
VM & P Naphtha	29.00%
Mineral spirits	12.00
Xylol	<5.00
D-100	<5.00
8. Scuff resistant medium gloss black enamel	
Xylene	38.00%
Heavy aromatic naphtha (D-129)	7.00
VM & P Naphtha	5.00
Ethylene glycol monoethyl ether acetate	4.50
Toluene	2.00
Mineral spirits	.50
9. Light buff primer	
Xylene	22.00%
Mineral spirits	7.00
VM & P Naphtha	9.00
Aromatic naphtha	5.50
Ortho alkylphenol guaiacol	< .50
Heptane	1.00
10. Industrial yellow (high solids)	
Xylene	24.00%
Ether alcohol	5.00
11. Heat resistant black	
Toluene	18.08%
Denatured ethyl alcohol	2.34
Isobutyl acetate	7.96
Xylene	19.49
Isobutyl alcohol	2.66
Super VM & P alcohol	17.80
N-butyl alcohol	1.43
Aromatic 100	4.82
Skelly-solve S	.15

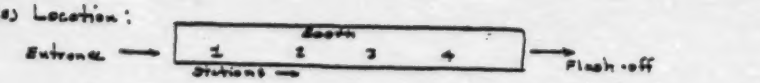
APPENDIX B

REVISED DATA GATHERING FORMS

Test Log Sheet. John Deere
Davenport WORKS
Recirculating Air Spray Booth

Date: _____
Test #: _____
Test Start time: _____
No. Sprayers: _____
Sprayer(s) Location: _____

- Sprayer(s) Location:



- Drum/Pot Locations and Color:
  - Pot # 1 outside Booth on North side, Green Ena.
  - Drum # 1 outside Booth on North side, yellow Ena.
  - Drum # 2 outside Booth on North side, yellow pri. Ena.
  - Drum # 3 Paint Mix Room; BLack, 270#
  - Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights (in inches):

	Pot 1	Drum 1	Drum 2	Drum 3	Drum 4
Paint Drum/Pot Ending Heights:					

Start Time	Sprayer # 1 Start	Sprayer # 1 Drum/Pot	Sprayer # 1 Stop	Sprayer # 2 Start	Sprayer # 2 Drum/Pot	Sprayer # 2 Stop	Notes:

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Time	Sensor # 2			Sensor # 2			Notes
	Start	Drum/Art	Stop	Start	Drum/Art	Stop	

APPENDIX C

PAINT AND STORAGE DRUM DATA

For reporting purposes, the five paint types used during the test were given a code based on storage containers to be used during the test procedure. The five codes used were:

P1 or P2:	Valspar AA 76419 fast dry green spray enamel
D1:	Dupont 917-104 Industrial yellow (high solids)
D2:	Moline Paint Manufacturing No. 2757 light buff primer
D3:	Moline Paint Manufacturing No. 2704 scuff resistant medium gloss black paint
D4:	Valspar 6AA102 green lead and chromate free primer

Reported densities for the five paints are:

P1:	8.32 lb/gal
D1:	specific gravity 1.3 = 10.84 lb/gal
D2:	9.96 lb/gal
D3:	8.53 lb/gal
D4:	8.95 lb/gal

Paints D1 through D4 were stored in drum containers with an inside diameter of 22". Pots P1 and P2 had an identicaql inside diameter of 11". To convert "dip" stick measurements into weight amounts of paint consumed, one uses the following relationship.

Weight amount of paint per unit level change
= (cross-sectional area of container) (unit height) (gal/ft^3) (density)

For P1 or P2 the calculation is:

$$\left(\frac{\pi}{4}\left(\frac{11}{12}ft\right)^2\right)\left(\frac{1}{12}ft\right) \quad (7.49\ gal/ft^3)(8.32\ lb/gal)$$

= 3.43 lb of paint/inch of level change

For D1 the calculation is:

$$\left(\frac{\pi}{4}\left(\frac{22}{12}\text{ft}\right)^2\right)\left(\frac{1}{12}\text{ft}\right)\ (7.49\ \text{gal/ft}^3)(10.84\ \text{lb/gal})$$

= 17.86 lb of paint/inch of level change

Corresponding relationships for D2, D3 and D4 are

D2 = 16.41 lb/inch
D3 = 14.05 lb/inch
D4 = 14.75 lb/inch

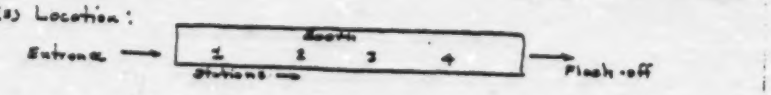
APPENDIX D

PAINT SPRAY BOOTH ACTIVITY MONITORING SHEETS

Davenport Works
Recirculating Air Spray Booth

Test #: 1 12/15/82
Test Start time: 11:15am
No. Sprayers: _____
Sprayer(s) location: _____

- Sprayer(s) Location:



- Drum/Pot Locations and Color:

Pot # 1 outside Booth on North side, Green Ena.
POT #2 outside Booth on South Side, Green Ena.
Drum # 1 outside Booth on North side, yellow Ena.
Drum # 2 outside Booth on North side, yellow pri. Ena.
Drum # 3 Paint Mix Room; Black, 2704
Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights:
  Paint Drum/Pot Ending Heights:
  (in inches)

	1 Pot 2'	Drum 1	Drum 2	Drum 3	Drum 4

(min) Start Time	Sprayer # 1 Start	Drum/Pot	Stop	Sprayer # 2 Start	Drum/Pot	Stop
01	1	D1	1	—	—	—
02	—	—	—	01	D1	04
03	3	Red	04.5	↓	↓	↓
04	↓	↓	↓			
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						
15						
16						
17						
18						

Notes:
in minute 3, don't know red

Test Log Sheet. John Deere
Davenport Works
Recirculating Air Spray Booth

Date: 12/29/82
Test #: 7
Test Start time: 12:25
No. Sprayers: 2
Sprayer(s) location: 2 3 2

- Sprayer(s) Location:

- Drum/Pot Locations and Color:

Pot # 1 outside Booth on North side, Green Ena.
Pot # 2 Outside Booth on South side Green Ena
Drum # 1 outside Booth on North side, yellow Ena.
Drum # 2 outside Booth on North side, yellow pri. Ena.
Drum # 3 Paint Mix Room; Black, 2704
Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights:
- Paint Drum/Pot Ending Heights:

(in inches)

Pot 1	Pot 2	Drum 1	Drum 2	Drum 3	Drum 4
0	0	0	0	0	0
3 ½	1 5/8	2	1 1/4	< ¼ avg.	4 ½

Start Time 12:25	Sprayer # 1			Sprayer # 2		
	Start	Drum/Pot	Stop	Start	Drum/Pot	Stop
	12:29	D4	12:30	12:29	D4	12:32
	12:30	D3	12:31	12:34	D3	12:35
	12:32	D3	12:33	12:36	D1	12:36
	12:34	D1	12:35	12:37	D4	12:41
	12:35	D4	12:40	12:42	D2	12:43
	12:40	D2	12:41	12:43	D3	12:44
	12:41	D3	12:47	12:46	D4	12:47
	12:44	D4	12:46	12:47	D2	12:48
	12:46	D2	12:47	12:49	D4	12:50
	12:47	D4	12:48	12:50	D2	12:51
	12:49	D2	12:49	12:51	D4	12:53
	12:49	D4	12:52	12:53	D1	12:55
	12:52	D1	12:53	12:55	D4	12:56
	12:53	D4	12:54	12:56	D1	12:57
	12:54	D1	12:55	12:57	D4	1:07
	12:55	D4	1:06	1:07	D1	1:08
	1:06	D1	1:06	1:08	D2	1:09
	1:07	D2	1:07	1:09	D4	1:10
	1:07	D4	1:08	1:10	D1	1:12
	1:09	D1	1:10	1:12	D4	1:13
	1:10	D4 D1	1:11	1:14	D1	1:16
	1:12	D4 D1	1:14	1:16	D2	1:16
	1:14	D4	1:16			

Notes:

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TEST 2, Pg. 2

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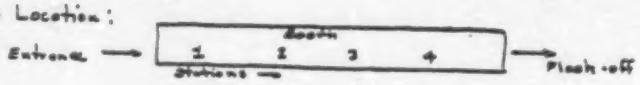
Time (sec)	Sprayer # 2 Start	Drum/Jet	Stop	Sprayer # 2 Start	Drum/Jet	Stop
22	1:16	D1	1:18	1:17	D4	1:18
23	1:18	D4	1:20	1:18	D1	1:21
24	1:20	D4	1:22	1:21	D4	1:24
25	1:23	D4	1:27	1:25	D4	1:28
26	1:27	D1	1:27	1:28	D1	1:29
27	1:28	D4	1:28	1:29	D4	1:31
28	1:28	D1	1:31	1:31	D1	1:33
29	1:31	D4	1:35	1:33	D4	1:37
30	1:35	P1	1:36	1:37	P1	1:38
31	1:37	D1	1:38	1:38	D1	1:40
32	1:38	D4	1:39	1:39	D4	1:40
33	1:39	D3	1:40			
34						
35						
36						
37						
38						
39						
40						
41						
42						
43						
44						
45						
46						
47						
48						

Notes

Test Log Sheet. John Deere
Davenport Works
Recirculating Air Spray Booth

Date: 12/15/92
Test #: 3
Test Start time: 11:30
No. Sprayers: 2
Sprayer(s) location: 1 & 2

- Sprayer(s) Location:



- Drum/Pot Locations and Color:

Pot # 1 outside Booth on North side, Green Ena.
Pot # 2 outside Booth on South side, Green Ena.
Drum # 1 outside Booth on North side, yellow Ena.
Drum # 2 outside Booth on North side, yellow pri. Ena.
Drum # 3 Paint Mix Room; BLack, 2704
Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights:
- Paint Drum/Pot Ending Heights:

(in inches)

	1 Pot 2		Drum 1	Drum 2	Drum 3	Drum 4
starting	-0-	-0-	> 1/4"	> no change	same	2"
ending	no change				none	

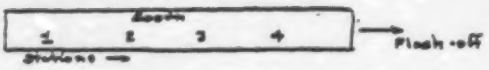
Start Time	Sprayer # 1 Start	Drum/Pot	Stop	Sprayer # 2 Start	Drum/Pot	Stop	Notes:
	00	D2	01	01	D1	04	
	03	D4	12	05	D4	13	
	13	D4	14	14	D4	16	
	16	D4	19	18	D4	24	
	20	D4	22	34	D4	38	activity stopped at minute 24
	33	D4	37	39	D1	40	" " " " 40
	37	D1	38				

Total activity time: 24
7
31

Test Log Sheet: John Deere
Davenport Works
Recirculating Air Spray Booths

Date: 12/16/82
Test #: 4
Test Start time: 8:22
No. Sprayers: 2
Sprayer(s) location: 1 & 2

- Sprayer(s) Location:



- Drum/Pot Locations and Color:

Pot # 1 outside Booth on North side, Green Ena.
Pot # 2 outside Booth on South side Green Ena
Drum # 1 outside Booth on North side, yellow Ena.
Drum # 2 outside Booth on North side, yellow pri. Ena.
Drum # 3 Paint Mix Room; BLack, 2704
Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights (in inches):

Pot 1	Pot 2	Drum 1	Drum 2	Drum 3	Drum 4
Light 1½"	N.C.	down 2¼"	N.C.	down 1"	down 4½"

Paint Drum/Pot Ending Heights: N.C. = no change

Start Time	Sprayer # 1 Start	Drum/Pot	Stop	Sprayer # 2 Start	Drum/Pot	Stop	Notes:
00	00	D4	00	00	D3	00	
	03	D4	05	01	D4	03	
	05	D1	06	05	D4	07	
	07	D3	08	08	D1	09	
	08	P7*	11	09	D3	10	spine chromate on #1, AA
	11	D3	13	13	D3	14	
	13	D3	15	16	D3	16	
	16	D1	21	22	D3	24	
	23	D3	24	24	D1	24	
	25	D3	26	25	D3	25	
	26	D4	30	39	D4	38	
	31	D4	36	44	D4	44	
	37	D4	42	44	D3	45	left booth at 48 min.
	42	D3	44				
	45	D1	46				
	76	D4	84	82	D4	82	restart
				83	D4	86	
	00	D3	00	00	D3	01	
	02	D1	03	02	D3	03	
	03	D4	06	04	D1	05	

see note next page

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Test 4 second page
12/16/82

Page ___ cont.

Time	Sensor # 2			Sensor # 3		
	Start	Drum/Art	Stop	Start	Drum/Art	Stop
				05	D4	08
	14	D1	15	15	D1	16
	15	D4	17	16	D4	19
	18	D4	19	20	D1	21
	19	D1	20	21	D3	24
	20	D3	21	24	D4	28
	22	D4	24	28	D1	31
	24	D1	25	31	D4	34
	25	D4	28			
	28	D1	30			
	30	D4	33			
	33	D1	34			

Notes

line shut down
reboot

manual 36 10 39

Total operating time: 45
10
34
84 min.

Test #5

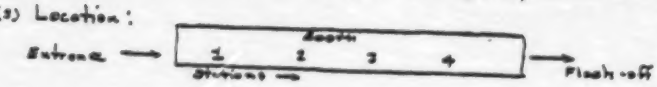
Pot #2	NO CHANGE
Drum #2	NO CHANGE
Drum #1	Down 2 1/4"
Pot #1	Down 1/2"
Drum #4	Down 4 1/2"
Drum #3	Down 1"

last log entry: [illegible]
Davenport Works
Recirculating Air Spray Booth

Test #: 5 12/14/82
Test Start time: 1:10 pm
No. Sprayers: 1
Sprayer(s) location: 1&2

Data for correlation between FID and booth activity

- Sprayer(s) Location:



- Drum/Pot Locations and Color:

Pot # 1 outside Booth on North side, Green Ena.
Pot # 2 outside Booth on South side, Green Ena
Drum # 1 outside Booth on North side, yellow Ena.
Drum # 2 outside Booth on North side, yellow pri. Ena.
Drum # 3 Paint Mix Room; Black, 2764
Drum # 4 Paint Mix Room; Green pri

- Paint Drum/Pot starting Heights:
  Paint Drum/Pot Ending Heights:

	Pot 1	Pot 2	Drum 1	Drum 2	Drum 3	Drum 4

(in inches)

Start Time	Sprayer # 1 Start	Drum/Pot	Stop	Sprayer # 2 Start	Drum/Pot	Stop
00 (1:10)	00	D4	01	00	—	01
	01	D1	02	01	D4	03
	02	—		03	D1	05
00	00	D3	01	00	D3	03
~~00~~	02	D4	06	04	D4	06
	06	D1	08	07	D1	09
	09	D4	15	10	D4	18
	15	D2	16	18	D1	20
	18	D4	20	20	D4	23
	21	D4	22			

Notes:

shutdown
restart 2:10

primer on No.1

Total Activity Time: 5
23
28

very active last

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APPENDIX E
SPECIALTY GAS CERTIFICATIONS

Scott Environmental Technology Inc.

Plumsteadville, PA 18949 (215) 766-8861
Troy, MI 48084 (313) 589-2950
San Bernardino, CA 92411 (714) 887-2571
SPECIALTY GAS DIVISION

Date: Sept. 21, 1981
Our Project No.: 45944
Your P.O. No.: AG7690-319

Engineering Science
125 W. Huntington
Arcadia, CA 91006

Gentlemen:

Thank you for choosing Scott for your Specialty Gas needs. The analyses for the gases ordered, as reported by our laboratory, are listed below. Results are in volume percent, unless otherwise indicated.

ANALYTICAL REPORT

Cyl. No. AAL7535 Analytical Accuracy ±1%

Component	Concentration
Methane	4981 PPM
Balance	Air

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Analyst _____

Approved By [signature]

The only liability of this Company for gas which fails to comply with this analysis shall be replacement thereof by the Company without extra cost.

ACCUFILL ■ CALIBRATION & SPECIALTY GAS MIXTURES ■ PURE GASES
ACCESSORY PRODUCTS ■ CUSTOM ANALYTICAL SERVICES

Scott Environmental Technology Inc.

Plumsteadville, PA 18949 (215) 766-8861
Troy, MI 48084 (313) 589-2950
San Bernardino, CA 92411 (714) 887-2571

SPECIALTY GAS DIVISION

ENGINEERING SCIENCE
125 W. HUNTINGTON
ARCADIA, CA. 91006

Date: 11-18-82
Our Project No.: 49160
Your P.O. No.: AG8027-320

Gentlemen:

Thank you for choosing Scott for your Specialty Gas needs. The analyses for the gases ordered, as reported by our laboratory, are listed below. Results are in volume percent, unless otherwise indicated.

ANALYTICAL REPORT

Cyl. No. AAL2633 — Analytical Accuracy ±2%

Component	Concentration
M-XYLENE	1040 PPM
AIR	BALANCE

Cyl. No. AAL1082 — Analytical Accuracy ±2%

Component	Concentration
METHANE	110.0 PPM
AIR	BALANCE

Cyl. No. _____ — Analytical Accuracy _____

Component	Concentration

Cyl. No. _____ — Analytical Accuracy _____

Component	Concentration

Analyst _____

Approved By James Ross

The only liability of this Company for gas which fails to comply with this analysis shall be replacement thereof by the Company without extra cost.

CERTIFIED REFERENCE MATERIALS • EPA PROTOCOL GASES
ACCREDITED CALIBRATION • SPECIALTY GAS MIXTURES • PURE GASES
ACCESSORY PRODUCTS • CUSTOM ANALYTICAL SERVICES

Scott Environmental Technology Inc.

Plumsteadville, PA 18949 (215) 766-8861
Troy, MI 48084 (313) 589-2950
San Bernardino, CA 92411 (714) 887-2571
SPECIALTY GAS DIVISION

ENGINEERING SCIENCE
125 W. HUNTINGTON
ARCADIA, CA. 91006

Date: 12-6-82
Our Project No.: 49237
Your P.O. No.: AGB027-320

Gentlemen:

Thank you for choosing Scott for your Specialty Gas needs. The analyses for the gases ordered, as reported by our laboratory, are listed below. Results are in volume percent, unless otherwise indicated.

ANALYTICAL REPORT

Cyl. No. AAL7191 Analytical Accuracy ±2%

Component	Concentration
XYLENE	1,145 PPM
AIR	BALANCE

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Cyl. No. _____ Analytical Accuracy _____

Component	Concentration

Analyst _____

Approved By James Ross

The only liability of the Company for gas which fails to comply with this analysis shall be replacement thereof by the Company without extra cost.

CERTIFIED REFERENCE MATERIALS ■ EPA PROTOCOL GASES
ACUBLEND® ■ CALIBRATION ■ SPECIALTY GAS MIXTURES ■ PURE GASES
ACCESSORY PRODUCTS ■ CUSTOM ANALYTICAL SERVICES

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Scott Environmental Technology Inc.

Plumsteadville, PA 18949 (215) 766-8861
Troy, MI 48084 (313) 589-2950
San Bernardino, CA 92411 (714) 887-2571

SPECIALTY GAS DIVISION

Engineering Science
125 W. Huntington
Arcadia, CA 91006

Date: April 16, 1981
Our Project No.: 44969
Your P.O. No.: AG2450-348

Gentlemen:

Thank you for choosing Scott for your Specialty Gas needs. The analyses for the gases ordered, as reported by our laboratory, are listed below. Results are in volume percent, unless otherwise indicated.

ANALYTICAL REPORT

Cyl. No. CAL6147 — Analytical Accuracy +2%

Component	Concentration
Methane	10.1 PPM
Balance	Air

Cyl. No. CAL6146 — Analytical Accuracy +2%

Component	Concentration
Methane	100 PPM
Balance	Air

Cyl. No. CAL6192 — Analytical Accuracy +2%

Component	Concentration
Methane	1005 PPM
Balance	Air

Cyl. No. _____ — Analytical Accuracy _____

Component	Concentration

Analyst _____

Approved By Jon Post

The only liability of this Company for gas which fails to comply with this analysis shall be replacement thereof by the Company without extra cost.

ACUBLEND ® CALIBRATION & SPECIALTY GAS MIXTURES ® PURE GASES
ACCESSORY PRODUCTS & CUSTOM ANALYTICAL SERVICES